DOCUMENT RESUME

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INSTITUTION Chief of Naval Education and Training Support, Pensacola, Fla.: Ohio State Univ., Columbus. National Center for Research in Vocational Education.

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ABSTRACT

This individualized learning module on the relationships of current, voltage, and resistance is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Five lessons are included in the module: (1) Voltage, Resistance, and Current, (2) The Ohm's Law Formula, (3) Power, (4) Internal Resistance, and (5) Troubleshooting Series Circuits. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks are provided for each lesson in a separate document, CE 026 562.) (LRA)

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CE 026 567

NAVEDTRA 34258-5

CHIEF OF NAVAL EDUCATION AND TRAINING

MARCH 1977

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS INDIVIDUALIZED LEARNING SYSTEM.

MODULE FIVE. RELATIONSHIPS OF CURRENT, VOLTAGE, AND RESISTANCE.

STUDY BOOKLET.

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE NATIONAL INSTITUTE OF EDUCATION

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THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

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The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

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The National Center for Research in Vocational Education
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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

O V E R V I E W

MODULE FIVE

RELATIONSHIPS OF CURRENT, VOLTAGE, AND RESISTANCE

In this module you will learn the relationships between current, voltage, and resistance in a series circuit. You will discover how to determine the values of current, voltage, resistance, and power in resistive series circuits. You will discover the effects of source internal resistance and be introduced to the troubleshooting of series circuits.

For you to more easily learn the above, this module has been divided into the following five lessons:

Do not be concerned at this time with names or terms unfamiliar to you. Each will become clear as you proceed. However, if you have any questions, do not hesitate to call your instructor. Turn to the following page and begin Lesson I.

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BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE FIVE

LESSON I

<u>Voltage, Resistance, and Current</u>

Study Booklet

OVERVIEW

LESSON 9

Voltage, Resistance, and Current

In this lesson, you will study and learn about the following:

-how voltage affects current
-how resistance affects current

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON 1

Voltage, Resistance, and Current

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics, Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

Film: Voltage & Current

Remember, you may study all or any of these that you feel are necessary to answer all Progress Check questions correctly. Do not forget that in one sense of the word your instructor is a living resource; perhaps the best. Call him if you have any kind of a problem.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

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NARRATIVE
LESSON I

Voltage, Resistance, and Current

You recall, no doubt, that you cannot do much directly to current that will change it. You must change the applied voltage, the circuit resistan e, or both to make current either increase or decrease. This rule applies to circuits with either DC or AC sources. The relationship of voltage, resistance, and current is probably the most important concept you will learn in your study of electricity.

Voltage Affects Current

In studying the effects of voltage and resistance upon current, we will examine them one at a time. First you will learn about the effect of voltage upon current, using a circuit with a fixed (unchanging) resistance and a varying source of voltage.

Using Practice Board 0-1, a 100-ohm resistor, and one dry cell, build a series circuit. Measure the current in this circuit. (Remember that current is the same throughout a series circuit.)

____

Now add another dry cell in series with the first to double the applied voltage. Measure the current now that the voltage has been increased. Record this current.

____

Add a third dry cell and measure the current flow.

____

In each of the steps above, the current flow increased because an increased force moved the electrons around the circuit faster (more flow per second).

Now, remove one of the cells and measure the current again. How does this current value compare to the last reading you made? __________

The observations you made should have led you to two conclusions about voltage and current. These conclusions could be stated as follows:

When voltage goes up, current goes up; when voltage

goes down, current goes down. A more accurate statement might be, when resistance is held constant, an increase in voltage causes an increase in current, and a decrease in voltage causes a decrease in current. Still another way of expressing this is that voltage and current are directly proportional.

Resistance Affects Current

When resistance is held constant, current varies in direct porportion to voltage, as you learned in the last section. The question now is what happens when resistance changes. To answer this question, you will study a circuit with constant voltage but varying values of resistance.

Using Practice Board 0-1, a 4.7-ohm resistor, and one dry cell, build a series circuit. Measure the current flow and record it here. ________

Now add another 4.7-ohm resistor in series with the first one. This will double the total resistance of the circuit. Measure and record this current. ________ Did the current increase or decrease. ________

Add another series resistor (10Ω) and measure the current. Is this result consistent with the first two readings?

____

If you didn't make any mistakes, you found that as resistance increased in a circuit, the current decreased. This relationship is called an inverse proportion; when one value goes up, the other goes down.

Check this conclusion by removing the resistors one at a time and measuring current flow. Do not try to measure current in the circuit with no resistor.

Resistance and EMF are inherent electrical quantities of the components we are using, and you cannot change the value of resistance or voltage without changing the basic form of the components. Current, on the other hand, is a secondary characteristic which depends on the values of resistance and voltage in the circuit. To repeat a statement made earlier, current can be readily changed only by physically changing the amount of voltage or the amount of resistance or both quantities in a circuit.

Summary

If resistance is constant in a circuit, more EMF will produce more current and less EMF will result in less current, or voltage and current are directly proportional.

If applied voltage is held constant in a circuit, an increase in resistance will cause current to decrease, and reducing the resistance will permit a greater current flow, or resistance and current are inversely proportional.

These relationships were discovered by George Simon Ohm, who formulated a statement covering all the quantities. This statement, called Ohm's Law, is: "Current is directly proportional to voltage and inversely proportional to resistance." This is one of the important laws you will learn about electricity. All your future studies and all the laws and rules you will learn can be traced back to this basic relationship if you look at them closely. Even more complex circuits can be covered by generalized forms of Ohm's Law.

Exercises

Answer all the questions below with the words increases, decreases, or does not change.

1. If EMF is increased from 6 v to 12 v and resistance is constant, what happens to current? ________
2. If the resistance is decreased from 5 ohms to 2 ohms and voltage is held constant, what will happen to the current? ________
3. If applied voltage is changed from 6 v to 12 v and current increases proportionally, what happens to resistance? ________
4. If you add a light bulb in series with one already in a circuit, what will happen to circuit current ________. To applied voltage? ________
5. If you change the EMF in a circuit from 12 v to 6 v while the resistance remains unchanged, what happens to the current? ________

ANSWERS:
1. increases
2. increases
3. does not change (resistance can be changed only through a mechanical change to the circuit)
4. decreases; does not change
5. decreases

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AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

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PROGRAMMED INSTRUCTION
LESSON I

Voltage, Resistance, and Current

TEST FRAMES ARE 6, 21, 32, 39, AND 40. AS BEFORE, GO FIRST TO TEST FRAME 6 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Recall that the magnitude of current is measured in amperes.

   Which correctly matches current to its unit of measurement symbol?

   ___ a. I - v
   ___ b. E - a
   ___ c. I - a
   ___ d. E - I

(c) I - a

---

2. Recall that the unit of measurement for E is represented by either a capital V or small letter v.

   V is the symbol for unit of:

   ___ a. current.
   ___ b. voltage.
   ___ c. resistance.
   ___ d. EMF.

(b. voltage; d. EMF)

---

3. Match the abbreviation for current and voltage to its correct unit of measurement symbol.

___ 1. E	a. v
___ 2. I	b. Q
	c. A
	d. a

(1. a; 2. d)

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4. The symbol used to represent the ohm is the Greek Letter omega or Ω.

Ω is the symbol for unit of:

___ a. I
___ b. R
___ c. E
___ d. V

(b) R

5. Which correctly matches the letter abbreviations to their appropriate unit of measure?

___ a. E - volts
I - amps
R - ohms
___ b. E - amps
R - volts
I - ohms
___ c. I - amps
R - ohms
E - ampéres
___ d. R - ohms
I - volts
E - amps

(a) E - volts; I - amps; R - ohms

6. Match the abbreviations and unit of measurement symbols to the correct descriptive phrase.

___	1. abbreviation for resistance	a.	V
___	2. abbreviation for voltage.	b.	I
___	3. measurement symbol for resistance	c.	R
___	4. measurement symbol for current	d.	E
___	5. abbreviation for current	e.	Ω
___	6. measurement symbol for voltage	f.	a

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

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ANSWERS - TEST FRAME 6

1. c
2. d
3. e
4. f
5. b
6. a

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME I AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 6 AGAIN.

7. Recall that current cannot be changed by itself. Current can only be increased or decreased by changing voltage or resistance or both.

Which statement or statements are true?

___ a. Current can be changed by increasing or decreasing E_a.
___ b. Current can only be changed by increasing or decreasing circuit resistance.
___ c. Current can be changed by keeping voltage and resistance the same.
___ d. I can be changed by changing either R or EMF or both.

(a. Current can be changed by increasing or decreasing E_a; d. I can be changed by changing either R or EMF or both.

8. The amount of current flow in a series circuit depends on:

___ a. the particular point in the circuit where I is measured.
___ b. circuit resistance and voltage.
___ c. whether source voltage is DC or AC.
___ d. the number of paths through which current is directed.

(b) circuit resistance and voltage

9. Applied voltage (E_a) is the force used to push electrons through the conductor. If R is not changed and applied voltage is increased, the force pushing the electrons becomes greater, and the electrons move around the circuit at a faster rate.

When E_a is increased:

___ a. I is increased.
___ b. I is decreased.
___ c. I stays the same.

(a) I is increased

10. Voltage can be increased by adding more cells to the circuit.

Which dry cell or cells will produce the most current flow?

(Assume that the resistance is constant.)

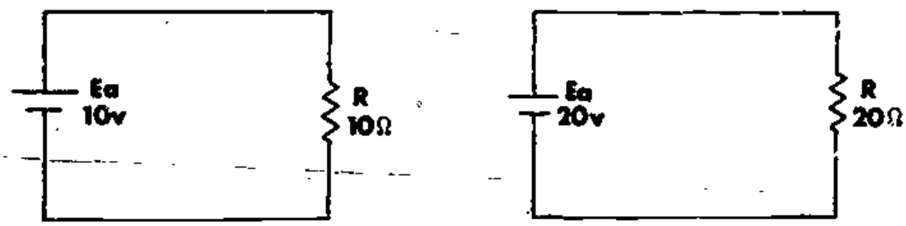
___ a. 1-1/2v cell
___ b. three 1-1/2v cells connected in series
___ c. two 1-1/2v cells connected in series
___ d. three 1-1/2v cells connected in parallel

(b) three 1-1/2v cells connected in series

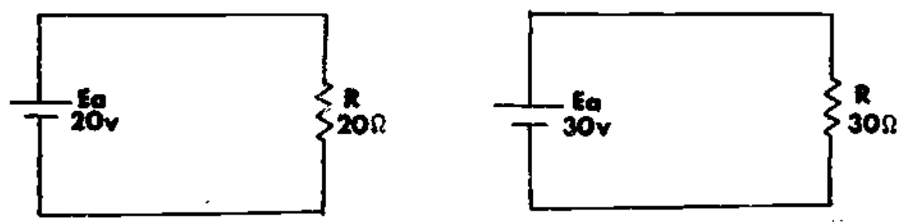
11. When resistance is constant and voltage is increased, current is also increased.

Which pair of schematics illustrates this rule?

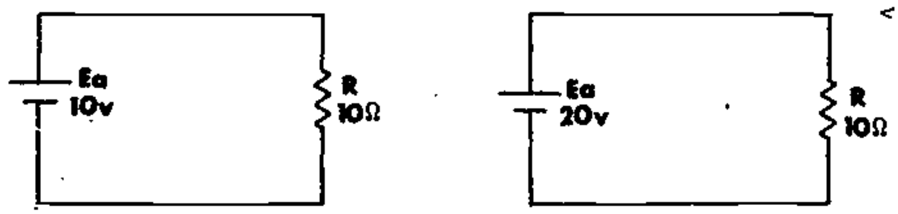
a.



b.



c.



(c)

12. When E is increased:

___ a. I will increase if R is kept constant.
___ b. I will decrease if R is kept constant.
___ c. I will remain the same.

(a) I will increase if R is kept constant

13. Since current increases when voltage is increased (and resistance is held constant), you can infer that:

___ a. current will go down when voltage goes down.
___ b. I will decrease when E is decreased.
___ c. I will decrease when E is increased.
___ d. less current will result as larger voltages are applied.

(a. current will go down when voltage goes down; and, b. I will decrease when E is decreased.)

14. When E is decreased and R is held constant:

___ a. I will stay the same.
___ b. I will decrease.
___ c. I will increase.

(b) I will decrease

15. Another way of saying that when voltage increases, current increases and when voltage decreases, current decreases is: voltage and current are directly proportional.

Which correctly describes the proportional relationship of voltage and current?

___ a. increasing E increases I;
decreasing E decreases I.
___ b. when voltage goes up, current goes up;
when voltage goes down, current goes up.

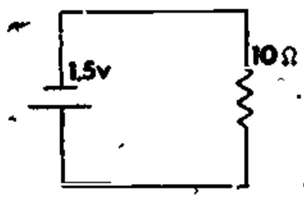
(a) increasing E increases I;
decreasing E decreases I.

16. Current goes up or down in ___________ ___________ to applied voltage as long as resistance is constant.

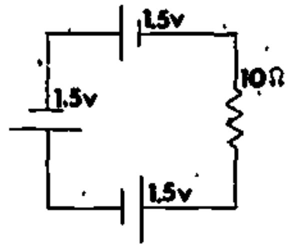
(direct proportion)

17. Which circuit would have the greatest current flow?

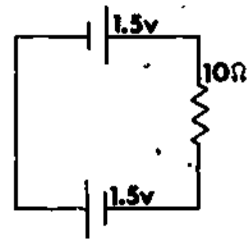
___ a.



___ b.



___ c.



(b)

18. Refer to frame 17. Which circuit would have the least current flow?

___ a. circuit a.
___ b. circuit b.
___ c. circuit c.

(a) circuit a

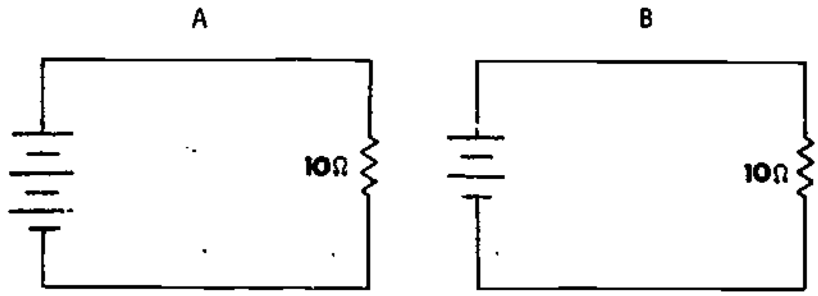
19. Match:

___ 1. In a series circuit, if R is constant and E_a is changed from 20v to 10v,
___ 2. In a series circuit, if R is constant and E_a is changed from 10v to 20v,

a. I will increase.
b. I will decrease.
c. I will not change.

(1. b; 2. a)

20. Study the two schematics, then check the statements that are correct. (All cells are alike.)



___ a. If you were to build circuits A and B, I in circuit B would be greater than I in circuit A.
___ b. If you were to build circuits A and B, I in circuit A would be greater than I in circuit B.

(b) If you were to build circuits A and B, I in circuit A would be greater than I in circuit B

21. Check the statements which describe directly proportional relationships.

___ a. Voltage increases, current decreases.
___ b. E increases, I increases.
___ c. E decreases, I increases.
___ d. Voltage increases, current decreases.
___ e. Voltage increases, current increases.
___ f. E increases, I decreases.
___ g. E decreases, I decreases.
___ h. Voltage decreases, current increases.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 21

b. E increases, I increases.

e. Voltage increases, current increases.

g. E decreases, I decreases.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 32. OTHERWISE, GO BACK TO FRAME 7 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

22. In a series circuit, as voltage increases, current also increases, showing a ____________ ____________ relationship.

(directly proportional)

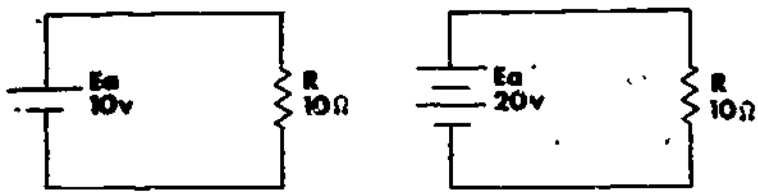
23. Define directly proportional in your own words. ____________

(two quantities which move in the same direction at the same time, or words to that effect)

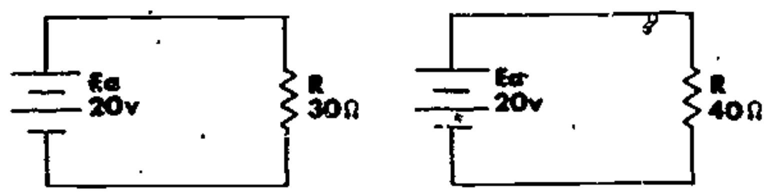
24. Current can also be changed by keeping voltage constant and varying resistance.

Which pair of schematics illustrates this rule?

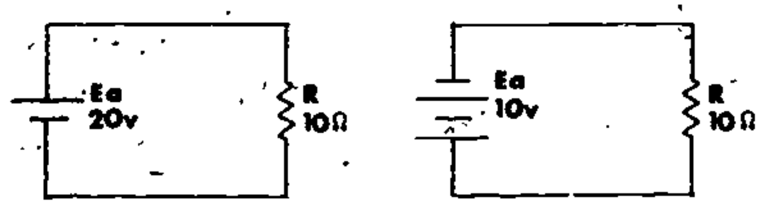
___ a.



___ b.



___ c.



(b)

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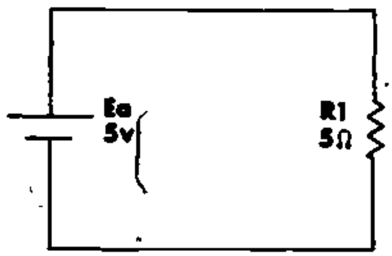
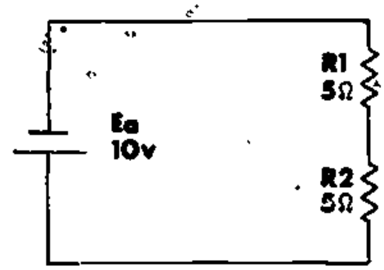
25. Resistance can only be changed by physical means. To change the resistance in a circuit, a variable resistor may be used or resistors may be added to or removed from the circuit.

Which of the following would have the most resistance?

____ A



____ B



(B)

26. Resistance is opposition to current flow. It tries to hold back or slow current.

If resistance in a circuit is increased by adding another resistor, and the voltage is kept constant, the current will:

____ a. increase.
____ b. decrease.
____ c. stay the same.

(b) decrease

27. Current will decrease:

____ a. when R is constant and E is increased.
____ b. when E is constant and R is decreased.
____ c. when E is constant and R is increased.
____ d. when R and E are equal.

(c) when E is constant and R is increased

28. When voltage is kept constant and resistance is decreased, current flow will meet less opposition.

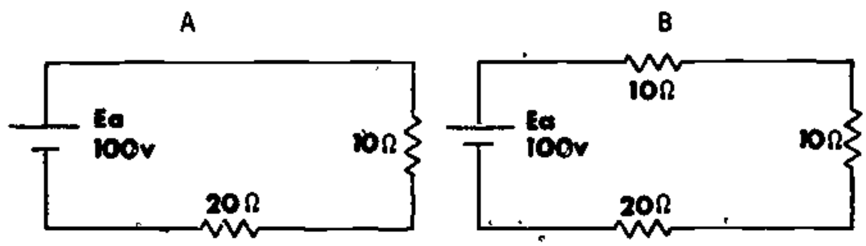
This means that current will:

___ a. increase.
___ b. decrease.

- -

(a) increase

29. Study the schematics, then check the correct statement.



___ a. If you were to build circuits A and B, I in circuit B would be greater than I in circuit A.
___ b. If you were to build circuits A and B, I in circuit A would be greater than I in circuit B.

- -

(b) If you were to build circuits A and B, I in circuit A would be greater than I in circuit B

30. Resistance and current are inversely proportional to each other. This means that as resistance goes up, current goes down, and as resistance goes down, current goes up.

Which correctly describes inversely proportional relationships?

___	a.	more E	more I
		less E	less I
___	b.	more R	less I
		less R	more I

- -

(b) more R less I; less R more I

31. Match:

___ 1. In a series circuit, if E is constant and R_T (total resistance) is changed from 100 ohms to 200 ohms,

___ 2. In a series circuit, if E is constant and R_T (total resistance) is changed from 200 ohms to 100 ohms,

a. I will not change.

b. I will decrease.

c. I will increase.

- -

(1. b; 2. c)

32. Check the statements that correctly describe inversely proportional relationships.

___ a. R increases, I increases.

___ b. R decreases, I increases.

___ c. Resistance increases, current decreases.

___ d. Resistance decreases, current decreases.

___ e. Resistance decreases, current increases.

___ f. R increases, I decreases.

___ g. R decreases, I decreases.

___ h. Resistance increases, current increases.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 32

b. R decreases, I increases.

c. Resistance increases, current decreases.

e. Resistance decreases, current increases.

f. R increases, I decreases.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 39. OTHERWISE, GO BACK TO FRAME 22 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 32 AGAIN.

33. Define inversely proportional in your own words. ______

(As one quantity increases, the other quantity will decrease; or words to that effect)

34. Match:

___ 1. In a series circuit, if E_a is constant, and R_T goes down from 10 ohms to 5 ohms,

___ 2. In a series circuit, if R_T is constant, and E_a goes up from 5 volts to 10 volts,

___ 3. In a series circuit, if R_T is constant, and E_a goes down from 10 volts to 5 volts,

___ 4. In a series circuit, if E_a is constant, and R_T goes up from 5 ohms to 10 ohms,

a. I will increase.

b. I will decrease.

(1. a; 2. a; 3. b; 4. b)

35. The relationships between current, voltage, and resistance were discovered by George Simon Ohm.

Which statement correctly expresses Ohm's Law?

___ a. Current is directly proportional to voltage and inversely proportional to resistance.
___ b. Current is inversely proportional to voltage and directly proportional to resistance.

(a) Current is directly proportional to voltage and inversely proportional to resistance.

36. "Current is directly proportional to voltage and inversely proportional to resistance" is a statement of ________.

(Ohm's Law)

37. Which of the following illustrates Ohm's Law?

___ a. E constant with less R results in more I.
___ b. R constant with more E results in less I.
___ c. R constant with less E results in less I.
___ d. E constant with more R results in less I.

(a. E constant with less R results in more I.; c. R constant with less E results in less I.; d. E constant with more R results in less I.)

38. State Ohm's Law: ________________________________

(Current is directly proportional to voltage and inversely proportional to resistance.)

31

39. Check the statements which illustrate Ohm's Law.

___ a. If R is constant and E is increased, then I will decrease.

___ b. If E is constant and R is increased, then I will increase.

___ c. If E is constant and R is decreased, then I will increase.

___ d. If R is constant and E is increased, then I is increased.

___ e. If E is constant and R is decreased, then I is decreased.

___ f. If R is constant and E is decreased, then I is increased.

___ g. If R is constant and E is decreased, then I is decreased.

___ h. If E is constant and R is increased, then I is decreased.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 39

c. If E is constant and R is decreased, then I will increase.

d. If R is constant and E is increased, then I will increase.

g. If R is constant and E is decreased, then I is decreased.

h. If E is constant and R is increased, then I is decreased.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY ON TO TEST FRAME 40. OTHERWISE, GO BACK TO FRAME 33 AND TAK. HE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 39 AGAIN.

In this frame sequence, you have learned about Ohm's Law, that is, current is directly proportional to voltage and inversely proportional to resistance.

This is the most important law you will learn in this course. You will need to understand the relationships between I, E, and R and to apply this understanding in any rating you go into. Because of the importance of Ohm's Law, see if you can answer the test frame on the following page before proceeding to the Progress Check.

40. Answer the following problems.

a. If E is increased from 6 volts to 12 volts and R is constant, what happens to I? ________________

b. If R is decreased from 10 ohms to 5 ohms and E is constant, what happens to I? ________________

c. If E is changed from 12 volts to 6 volts, and I decreases proportionately, what happens to R? ________________

d. If you add a second light bulb to a circuit, what happens to I and applied voltage? ________________

e. If you change E_a from 12 volts to 6 volts and R is constant, what happens to I? ________________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 40

a. increases

b. increases

c. Nothing; R is a physical property and its ohmic value cannot be changed by changing voltage or current. Resistance can only be changed by physical change of components.

d. I decreases. E_a does not change since, like resistance, it can only be changed by physically increasing or decreasing the applied voltage.

e. decreases

IF ANY OF YOUR ANSWERS IS INCORRECT, TAKE THE PROGRAMMED SEQUENCE AGAIN.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

ERIC

SUMMARY
LESSON 1

Voltage, Resistance, and Current

The most important concept you must master in electricity is how voltage, current, and resistance are interrelated. The easiest way to study these relationships is to consider the effects of voltage on current first, then to study how resistance affects current, and finally to look at all three quantities together.

An experimenter working with electricity will, sooner or later, discover that changing the voltage applied to a circuit will cause the circuit current to change. For example, doubling the amount of voltage to a light bulb will cause it to glow much brighter (higher current) if the bulb doesn't burn out.

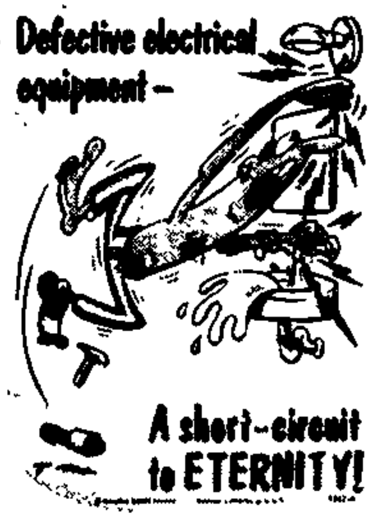
Using a fixed resistor, a number of dry cells, and an ammeter, you can demonstrate that the current in a circuit is proportional to the voltage applied to it. Doubling the voltage will cause the current to double, triple voltage will triple current, etc. This is called a direct proportion; when voltage increases, current increases; when voltage decreases, current decreases.

Changing the resistance in a circuit also causes current to vary. Increasing the resistance in a circuit with a constant voltage applied will decrease the current flow. Decreasing the resistance will permit current to increase. This is called inverse proportion. These changes are also in the same ratio; that is, doubling the resistance will halve the current flow or reducing the resistance to one-third will triple the current flow.

We used current as the dependent quantity in these examples because it is the one thing you cannot easily change in a circuit. Current may be changed only by changing the battery (voltage) or the resistance.

The relationships of voltage, resistance, and current were first discovered by George Simon Ohm. Ohm's Law states: "Current is directly proportional to voltage and inversely proportional to resistance." This law is basic to nearly all that you will study and learn about electricity/electronics in the future. It ca. be generalized to cover almost all types of complex circuits.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


Defective electrical equipment –
A short-circuit to ETERNITY!

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE FIVE

LESSON II

The Ohm's Law Formula

Study Booklet

OVERVIEW
LESSON II

The Ohm's Law Formula

In this lesson you will study and learn about the following:

- -need to calculate mathematically
- -mathematical formula
- -use of Ohm's Law to find voltage and resistance
- -applying Ohm's Law to parts of the circuit
- -complex solutions using Ohm's Law

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

ERIC

LIST OF STUDY RESOURCES
LESSON II

The Ohm's Law Formula

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

You may study whatever learning materials you feel are necessary to answer the questions in the Lesson Progress Check. All your answers must be correct before you can go to Lesson III. Remember your instructor is available at all times for any assistance you may need.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON II

The Ohm's Law Formula

Need to Calculate Mathematically

There will be times when you will need to determine the amount of current in a circuit, but it is not always convenient or possible to connect an ammeter into the circuit. For example, if you suspected the main supply current in a shipboard power distribution system was too high, you would have to shut down the circuit to check the current flow. This would cut off the functioning of all the equipment fed by that system, a <u>very</u> undesirable situation.

How, then, can you find out how much current is flowing? If you know (or can measure) the values of <u>EMF</u> and resistance, you can calculate the amount of current flow.

Mathematical Formula

Ohm's Law can be expressed as a formula using alphabetic symbols. This formula will let you find current flow when voltage and resistance are known. This "magic" formula is:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Written with the symbols for current, voltage, and resistance, this is:

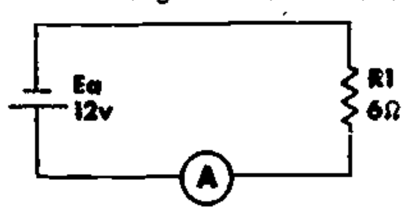
$$I = \frac{E}{R}$$

To make this formula work properly, all values must be given in their basic units of amperes, volts, and ohms. That is,

$$\text{Current (amperes)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

You will need to know the metric prefixes and powers of ten to keep your values in the proper units.

Here is an example of a use for the Ohm's Law formula: this circuit has a 12v battery forcing current through a 6-ohm resistor. What will the ammeter indicate?



The Ohm's Law formula is $I = \frac{E}{R}$. Substituting known values from the circuit in the formula yields:

$$I = \frac{12v}{6\Omega}$$

Dividing, the answer is: $I = 2a$.

Here are some more examples, this time using metric prefixes and powers of ten:

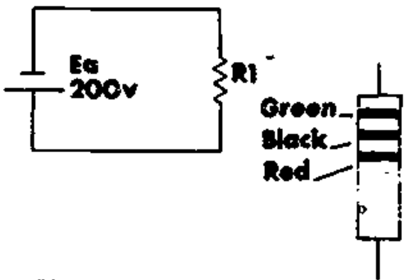
Find I.

$$I = \frac{E}{R}$$

$$I = \frac{250v}{500\Omega}$$

$$I = .5a \text{ or } I = 500ma$$

Find I in the following circuits.



$$I = \frac{200v}{5k\Omega}$$

$$I = \frac{200v}{5 \times 10^{3}\Omega}$$

$$I = 40 \times 10^{-3}a$$

$$I = 40ma$$

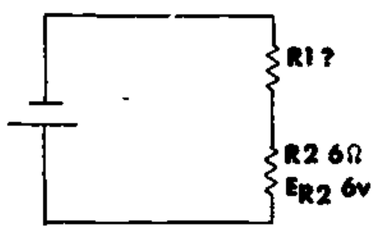
$$I = \frac{1000 \times 10^{-3}v}{10\Omega}$$

$$I = 100 \times 10^{-3}a$$

$$I = 100ma$$

Ohm's Law may be used to find the current in one part of a circuit when resistance and voltage for that part are known. Since current in a series circuit is the same throughout the circuit, the value you find is the same as the current in any other part of the series circuit.

Example: What is the current flow through R1?



$$I_{R2} = \frac{E_{R2}}{R2}$$

$$I_{R2} = \frac{6v}{6\Omega}$$

$$I_{R2} = 1a$$

I_{R2} equals I_{R1}, therefore $I_{R1} = 1a$

Solve for the current in each of the following problems.

1. A circuit containing 120 ohms of resistance has 60v applied to it. I = ________________

2.

I = ________

3.

I = ________

4.

I = ________

5.

I = ________

Answers:
1. .5a or 500 ma
2. 6a
3. 100ma
4. 10ma
5. 30μa

Using Ohm's Law To Find Voltage

You will occasionally need to find the voltage in a circuit when you know the current and the resistance. Transposition of the

terms of the Ohm's Law formula yields E = IR:

$$I = \frac{E}{R}$$

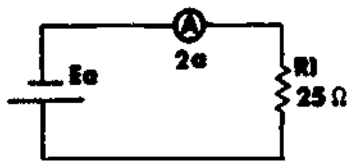
Multiply by R $\qquad RI = \frac{ER}{R}$

Cancel $\qquad RI = \frac{E\cancel{R}}{\cancel{R}}$

Giving $\qquad RI = E$ (or $E = IR$)

Voltage equals current times resistance.

An example of this solution:



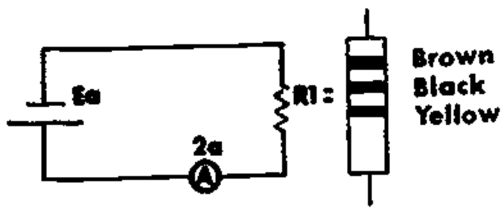
$E_a = IR$

$E_a = 2a \times 25\Omega$

$E_a = 50v$

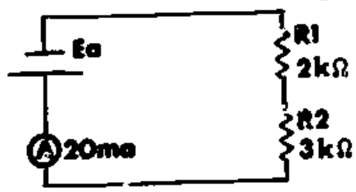
Find the applied voltage in each of these circuits.

1.



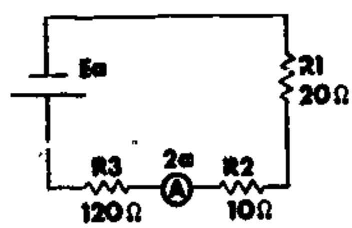
$E_a =$ ________

2.



$E_a =$ ________

3.



$E_a =$ ________

Answers: 1. E_a = 200kv

2. E_a = 100v

3. E_a = 300v

Finding Resistance

You can find the resistance of a circuit if the applied voltage and circuit current are given by using another Ohm's Law transposition.

$R = \frac{E}{I}$ allows for a direct solution for resistance. The transposition from Ohm's Law is done like this:

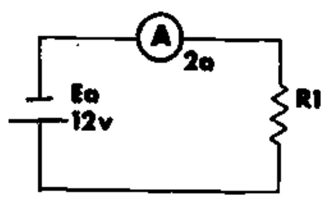
$$I = \frac{E}{R}$$

Multiply by R; divide by I $\qquad \frac{IR}{I} = \frac{ER}{RI}$

Cancel, giving $\qquad \frac{\cancel{I}R}{\cancel{I}} = \frac{E\cancel{R}}{\cancel{R}I}$

Resistance equals voltage divided by current $\qquad R = \frac{E}{I}$

For example:



Find the value of R1.

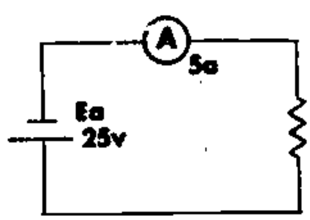
$$R1 = \frac{E}{I}$$

$$R1 = \frac{12v}{2a}$$

$$R1 = 6\Omega$$

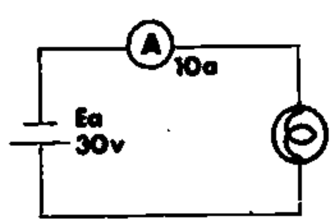
Practice on these problems.

1.



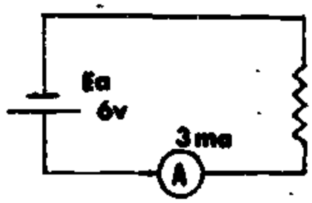
R = ________

2.



R = ________

3.



R = ________

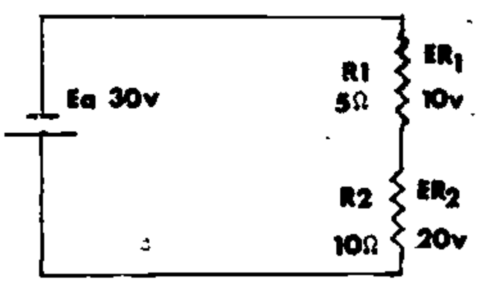
Answers: 1. R = 5Ω
2. R = 3Ω
3. R = 2kΩ

Applying Ohm's Law to Parts of the Circuit

Using the basic Ohm's Law ($I = \frac{E}{R}$) and the two transpositions ($E = IR$ and $R = \frac{E}{I}$), you can find the current, voltage, or resistance of any complete circuit. You can also find the current, voltage, or resistance of any part of a circuit by using these formulas. Of course, you still have to know two of the values for the part you are working with.

Example:

Solve for current. ________



Looking at this circuit, one component which has two known values is <u>R1</u>. From the voltage and resistance, current can be computed using $I = \frac{E}{R}$.

$I = \frac{E_{R1}}{R1}$ $\quad I = \frac{10v}{5\Omega}$ $\quad I = 2a$

You could start by finding the current through <u>R2</u> instead of <u>R1</u> as follows:

$I = \frac{E_{R2}}{R2}$ $\quad I = \frac{20v}{10\Omega}$ $\quad I = 2a$

Total circuit values could also have been used to find current. The applied voltage is given, and the total resistance can be calculated.

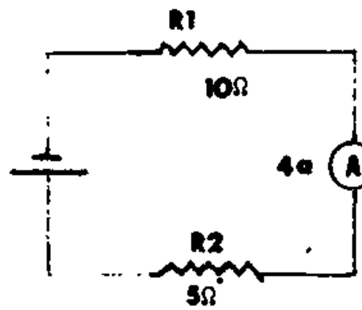
When a number of resistors are connected in series, their total resistance (R_T) equals the sum of individual resistances. Stated in symbols, this is $R_T = R1 + R2 + R3$, etc.

The total resistance in the circuit above is 5 ohms plus 10 ohms (or 15 ohms). Current can now be found by:

$$I = \frac{E_a}{R_T} \qquad I = \frac{30v}{15\Omega} \qquad I = 2a$$

The solutions to this problem show that, as we said earlier, current is the same in all parts of a series circuit.

The voltage across one component of a circuit can be found as follows:



To find E_{R2},

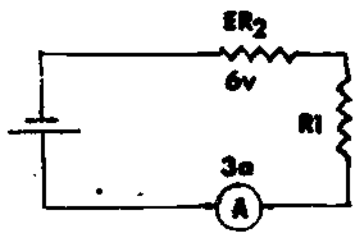
$E_{R2} = I \times R2$; $E_{R2} = 4a \times 5\Omega$; $E_{R2} = 20v$

To find E_{R1}

$E_{R1} = I \times R1$; $E_{R1} = 4a \times 10\Omega$; $E_{R1} = 40v$

Because the sum of the voltage drops equals the applied voltage, the applied voltage must be 60v (40v + 20v = 60v).

In the following series circuit, voltage and current are given, and you can find R by using Ohm's Law.

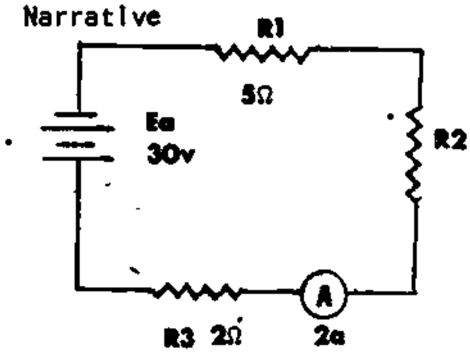


$$R1 = \frac{E_{R1}}{I} = \frac{6v}{3a} = 2\Omega$$

Since current is the same in all parts of a series circuit and the voltage drop across R2 is the same as the drop across R1, R2 must have the same value as R1. You can work out R2 using Ohm's Law if you wish to prove this shortcut.

Complex Solutions Using Ohm's Law

In most practical on-the-job situations, you will need a series of Ohm's Law solutions to find the particular quantity you need to know. Examine the circuit diagram below to locate some unknown quantity you can calculate from the given data.



Solve for R2.
In this case, you cannot find R2 directly from the information given, so it is necessary to look a little harder. Total resistance can be found from E_a and I.

$$R_T = \frac{E_a}{I} = \frac{30v}{2a} = 15\Omega$$

You learned earlier that the total resistance equals the sum of the resistors' values in a series circuit. If you write this as an equation, you get

$$R_T = R1 + R2 + R3$$

Substituting known values in this equation gives:

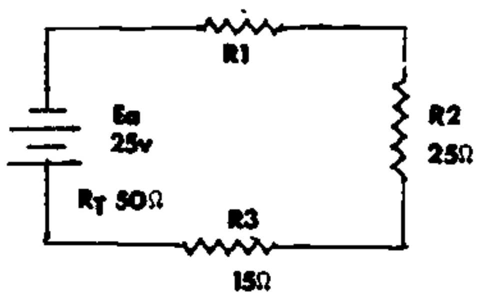
$$R_T = R1 + R2 + R3$$

$$15\Omega = 5\Omega + R2 + 2\Omega$$

Solving for R2:

$$R2 = 15\Omega - 7\Omega$$
$$R2 = 8\Omega$$

Another example which requires you to use Ohm's Law and the rules for series circuits is:



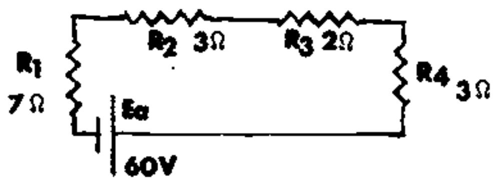
Solve for E_{R1}.

One way to find E_{R1} is to find the resistance of R1 and the current through it. From the given values, you know R1 equals $R_T - (R2 + R3)$ or 10 ohms. Current is found by dividing source voltage by total resistance and equals 0.5a. Then $E_{R1} = 0.5a \times 10\Omega = 5v$.

By doing a series of simple calculations like these, you will be able to find any quantity in a series circuit. There are two secrets to the procedure; first, look at the problem to see what values you need to know to get the answer. Second, look at the given terms to learn what values you can find.

Some of the following problems may take several steps to solve, so don't give up a procedure too quickly. Answers are given on the next page so you can check your work when you have finished a problem.

1.



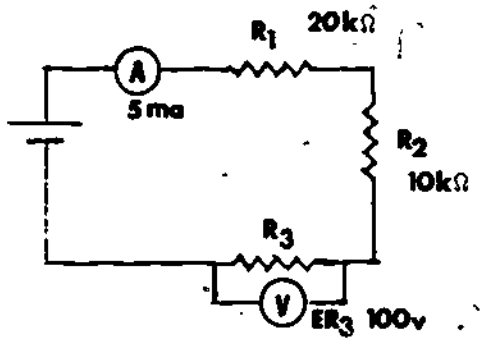
Find: I_T = E_{R2} =

R_T = E_{R3} =

E_{R1} = E_{R4} =

I_{R3} = I_{R4} =

2.



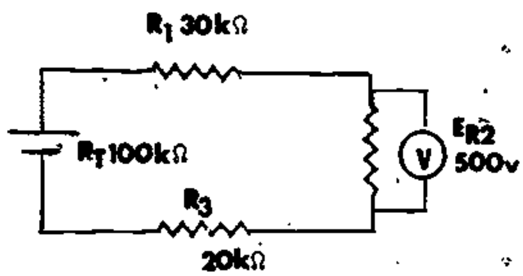
Find: I_T = I_{R2} =

E_{R2} = R_T =

R_3 = E_a =

E_{R1} =

3.

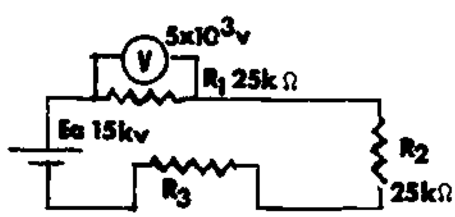


Find: R2 I_T

E_{R1} E_a

E_{R3} I_{R3}

4.



Find: I_T E_{R3}

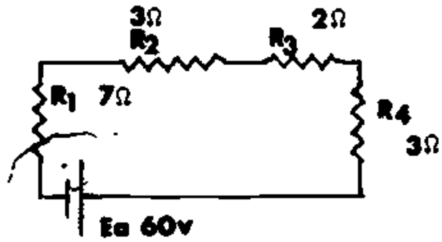
E_{R2} R_T

R3 I_{R3}

ANSWERS on next page.

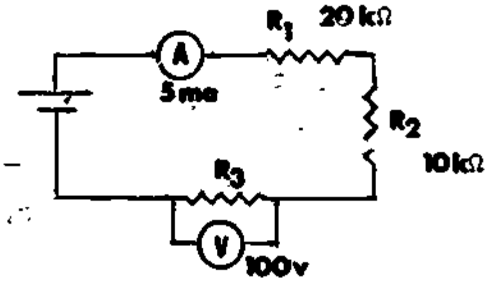
Answers:

1\.



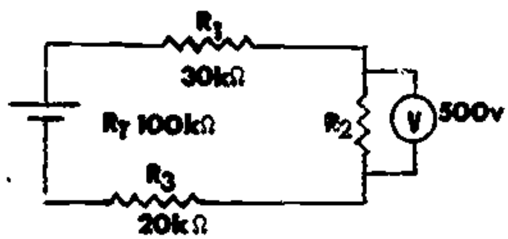
Find: I_T = 4a E_{R2} = 12v
R_T = 15Ω E_{R3} = 8v
E_{R1} = 28v E_{R4} = 12v
I_{R3} = 4a I_{R4} = 4a

2\.



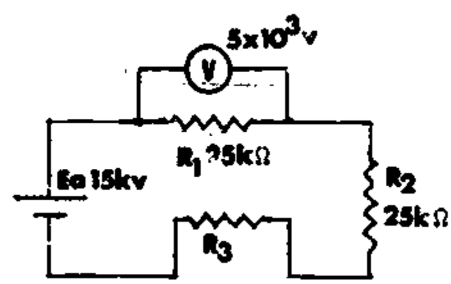
Find: I_T = 5ma I_{R2} = 5ma
E_{R2} = 50v R_T = 50kΩ
R_3 = 20kΩ E_a = 250v
E_{R1} = 100v

3\.



Find: R_2 = 50kΩ I_T = 10ma
E_{R1} = 300v E_a = 1kv
E_{R3} = 200v I_{R3} = 10ma

4\.



Find: I_T = 200ma E_{R3} = 5kv
E_{R2} = 5kv R_T = 75kΩ
R = 25kΩ I_{R3} = 200ma

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

The Ohm's Law Formula

TEST FRAMES ARE 9, 16, 21 AND 40. AS BEFORE, GO FIRST TO TEST FRAME 9 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. You have probably gained some idea of how current, voltage, and resistance affect one another in a circuit. An exact statement of this relationship is called Ohm's Law. Ohm's Law says that current in a circuit is directly proportional to the voltage applied and inversely proportional to the circuit resistance. In the form of an equation, it is:

$$I = \frac{E}{R}$$

Where I = current in amperes
E = voltage in volts
R = resistance in ohms

Write the equation for Ohm's Law: ______________

- -

($I = \frac{E}{R}$)

2. In your own words, state Ohm's Law: ______________

____

____

- -

(Current varies directly with the applied voltage and inversely with the circuit resistance, or words to this effect.)

3. The first part of the Ohm's Law statement (current is directly proportional to the applied voltage) means that if resistance is held constant and the voltage is increased the current will increase.

It follows then that if resistance is held constant and voltage is decreased, current will become ______________.
larger/smaller

- -

(smaller)

4. Since current is the result of applying a voltage across a resistance, it follows that current may be changed by changing either the voltage or the resistance. Current cannot be changed directly for it is not a thing which can be placed in a circuit like the resistor or the dry cell.

Current in a circuit may be changed only by changing either the ______________ or the ________________, or both.

(voltage; resistance [either order])

5. In a simple circuit, which of the following cannot be changed directly?

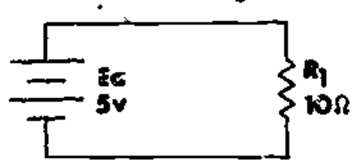
___ a. voltage
___ b. current
___ c. resistance

(b) current

6. Given a circuit containing a load device of 25 ohms and a source of 100 volts, what will be the current flow? ____________

$(I = \frac{E}{R} = \frac{100v}{25\Omega} = 4a)$

7. Using the formula $I = \frac{E}{R}$, find the current flowing in the following circuit.



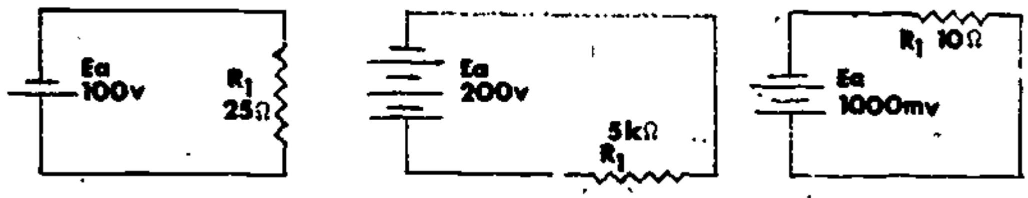
I = ________________

(I = 0.5a)

8. In a circuit with a load resistance of 500 ohms and a 45-volt source, the current will be ____________.

(0.09a or 90ma)

9. Solve each circuit for I.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 9

a. 4 a

b. 40 ma

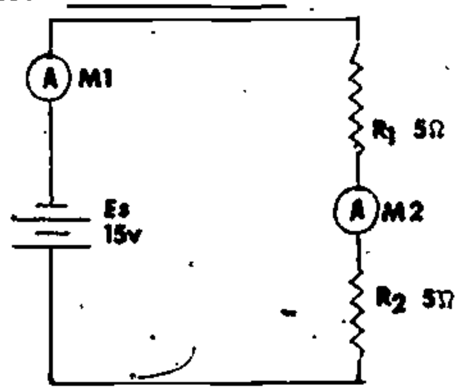
c. 100 ma

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 16. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 9 AGAIN.

10. As you have seen, current in a series circuit is common throughout the circuit.

In the circuit, ammeter 1 reads 1.5a.

What will ammeter 2 read? ____________



(1.5a)

11. Since current is the common factor in a series circuit, this allows us to use Ohm's Law to find the voltage and resistance.

Ohm's Law can be used to mathematically compute ____________, ____________, and ____________. (Any order.)

(current, voltage, resistance)

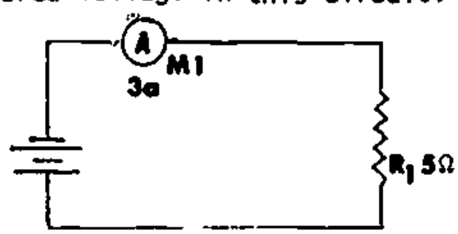
12. Ohm's Law enables you to find the current flow in a circuit when the voltage and resistance are known, but if the current and resistance are known you must rearrange the formula to obtain the unknown value. Multiplying the equation by R and cancelling gives E = IR. Voltage may now be easily calculated.

$$I = \frac{E}{R};\quad IR = \frac{ER}{R};\quad IR = E;\ \text{or}\ E = IR$$

Write the variation of the Ohm's Law equation which gives voltage directly. ____________

(E = IR)

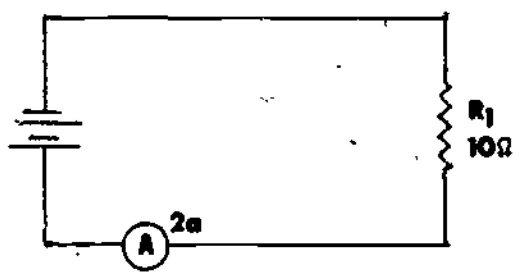
13. Find the source voltage in this circuit.



E_a = ____________

(15v)

14. Solve for the applied voltage in the following circuit.



E_a = ____________

(20v)

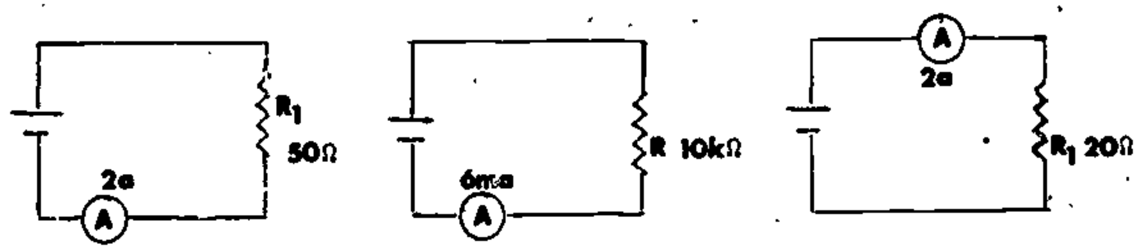
15. Determine the voltage required to cause 3 amperes of current to flow in a circuit containing a resistance of 25 ohms.

E_a = ____________

- -

(75v)

16. Determine the source voltage in the circuits below.



a. __________ b. __________ c. __________

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 16

a. 100v

b. 60v

c. 40v

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 21. OTHERWISE, GO BACK TO FRAME 10 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 16 AGAIN.

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17. In the same way, we may determine the resistance if voltage and current are known. Rearranging Ohm's Law to solve for resistance, we obtain the equation:

$$I = \frac{E}{R}; \quad RI = \frac{E\cancel{R}}{\cancel{R}}; \quad \frac{R\cancel{I}}{\cancel{I}} = \frac{E}{I}; \quad R = \frac{E}{I}$$

Write the result of solving Ohm's Law for resistance. ________

$(R = \frac{E}{I})$

---

18. If a circuit has a source of 30v and the current flow is 5a, what is the resistance of the circuit? ________

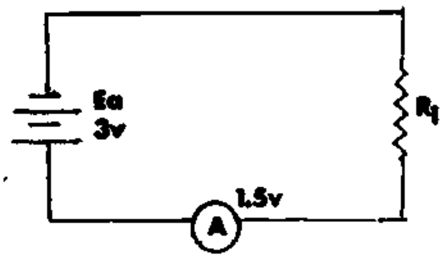
$(R_T = \frac{E}{I}, \quad R_T = \frac{30v}{5a}, \quad R_T = 6\Omega)$

---

19. Write the equation for Ohm's Law and the two variations used for finding resistance and voltage. ________

$(I = \frac{E}{R}; \quad R = \frac{E}{I}; \quad E = IR)$

20. What is the resistance of the load in the following circuit?

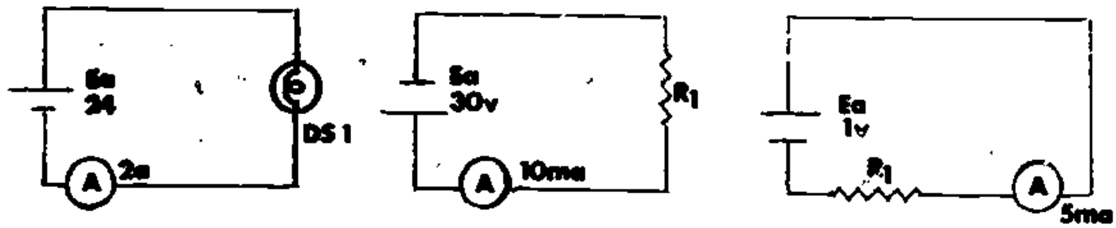


Rl = ____________________

- -

(2Ω)

21. Compute the resistance of the following:



a. ________ b. ________ c. ________

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 21

a. 12Ω

b. 3kΩ

c. 200Ω

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 40. OTHERWISE, GO BACK TO FRAME 17 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 21 AGAIN.

22. Now that you have covered the simple circuit, you are ready for circuits with more than one load component. The first such circuit you will learn is the series circuit, which is defined as a circuit which has only one path for current flow.

A circuit which has all of its components connected so that current must flow in only one path is called a ______________ circuit.

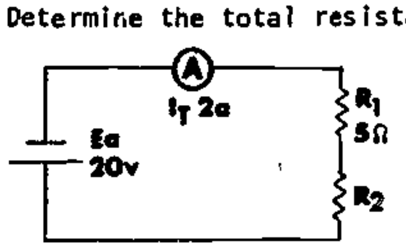
(series)

23. Define a series circuit. ______________________________

(A circuit with only one path for current flow)

24. To find the total resistance of a series circuit, divide the applied voltage by the current flow.

Determine the total resistance of the following:



R_T = ____________

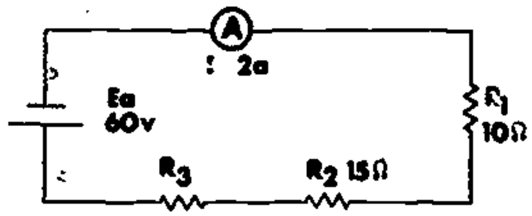
(10Ω)

25. The total opposition in the circuit is equal to the sum of the individual resistors.

What is the value of R2 in frame 24?

(5Ω)

26. Find the value of R3.



(5Ω. Note: You must first solve for R_T and then for R_3.)

27. You will recall that an EMF may be produced in various ways. Each of these methods converts some form of energy into electricity, an action which is called rise in potential.

The conversion of chemical action into an EMF is called ________.

(rise in potential)

28. Another way of saying this is to state that electrons within a source are raised to a higher energy state by the forces which move them from the positive terminal to the negative terminal.

The rise in potential is caused by (increasing/decreasing) the energy of electrons.

(increasing)

29. Name the action of converting some other form of energy into electricity. ________

(rise in potential)

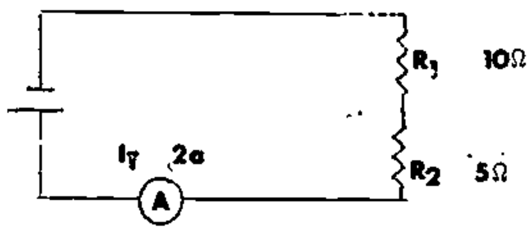
30. Just as a source of EMF leads to a rise in potential, the load in a circuit produces a fall in potential or conversion of electricity to some other form of energy. You may use these terms to further describe a voltage when you wish to make a strong distinction between a voltage generated within a source and a voltage drop occurring in a load. (Voltage drop is a commonly used term for fall in potential. In this case, the electrons moving through the load give up the energy they received from the source, and it is used as heat, light, etc.)

The action which changes electricity into some other form of energy is called ________________.

(fall in potential or voltage drop)

31. To find the voltage drop (or fall in potential) across a resistor or resistors simply multiply the current through the resistor by the resistance of the resistor.

For example: Find voltage drop across R1.



$E_{R1} = I \times R1$

$E_{R1} = (2a)(10\Omega)$

$E_{R1} = 20v$

Find the voltage drop across R2.

($E_{R2} = 10v$)

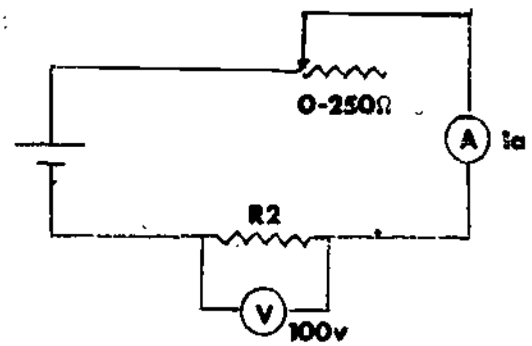
32. Using I_T and R_T in frame 31, find the applied voltage. ________

($E_a = 30v$)

33. Just as $R_T = R1 + R2 + R3$, the applied voltage must equal the sum of the voltage drops in a series circuit.

(E_a = 20v)

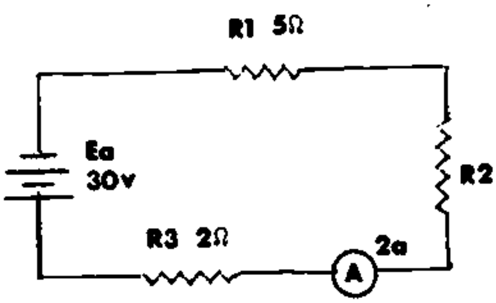
34. In the following circuit, what value must the variable resistor have in order to reduce the voltage drop across R2 by one half?



(100 Ω)

35. Frequently you will need to solve for one value before you can solve for another, because you must have two known values to solve for a third.

Example: Solve for <u>R2</u>.



In this circuit we have everything required to solve for R_T:

$$R_T = \frac{E_a}{I} = \frac{30v}{2a} = 15\Omega$$

Once R_T is found, finding <u>R2</u> is a simple matter of subtraction:

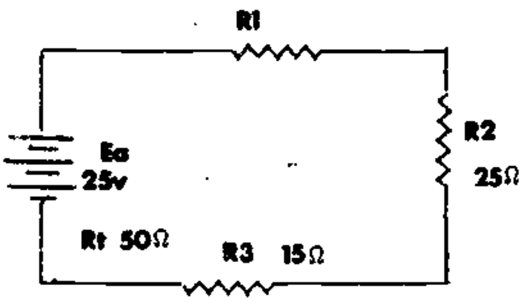
$$R2 = R_T - (R1 + R3)$$

$$R2 = 15\Omega - (5\Omega + 2\Omega)$$

$$R2 = 15\Omega - (7\Omega)$$

$$R2 = 8\Omega$$

Solve for E_{R1}.



In this circuit, we work the other way. We have all that is needed to find the value of both <u>R1</u> and current:

$$R_T - (R3 + R2) = R1$$

$$50\Omega - (15\Omega + 25\Omega) = R1$$

$$50\Omega - 40\Omega = R1$$

$$10\Omega = R1$$

$$I = \frac{E_a}{R_T} = \frac{25v}{50\Omega} = .5a$$

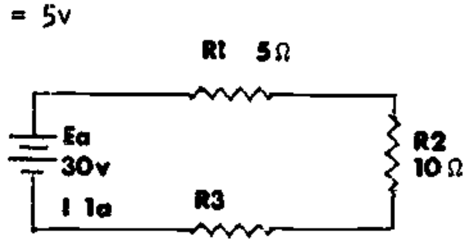
From this it is simply a matter of multiplication:

$$E_{R1} = (R1)(I)$$

$$E_{R1} = (10\Omega)(.5a)$$

$$E_{R1} = 5v$$

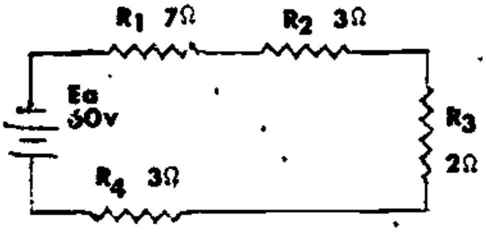
Solve for R_T:



- -

($R_T = 30\Omega$)

36. Using multiple calculations solve the following.



Find

a. I_T =

b. R_T =

c. E_{R1} =

d. I_{R3} =

e. E_{R2} =

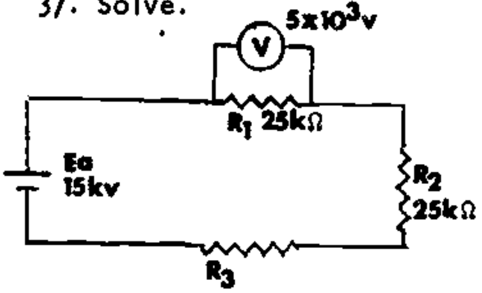
f. E_{R3} =

g. E_{R4} =

h. I_{R4} =

(a. 4a; b. 15Ω; c. 28v; d. 4a; e. 12v; f. 8v; g. 12v; h. 4a)

37. Solve.



Find

a. I_T =

b. E_{R2} =

c. R_3 =

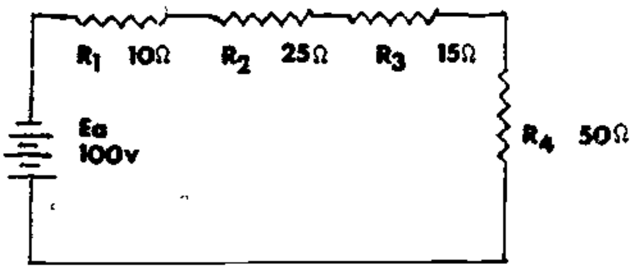
d. E_{R3} =

e. R_T =

f. I_{R3} =

(a. 200ma; b. 5kv; c. 25kΩ; d. 5kv; e. 75kΩ; f. 200ma)

38. Solve the circuit for quantities indicated.



a. R_T ______

b. I_T ______

c. E_{R1} ______

d. I_{R3} ______

e. E_{R2} ______

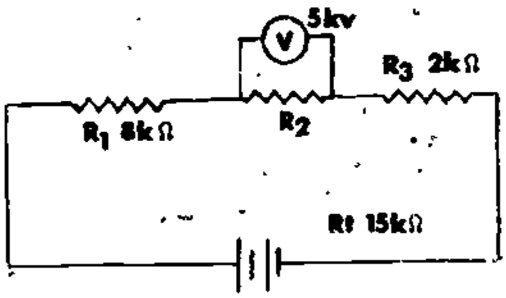
f. E_{R3} ______

g. E_{R4} ______

h. I_{R4} ______

(a. 100Ω; b. 1 amp; c. 10v; d. 1 amp; e. 25v; f. 15v; g. 50v; h. 1 amp)

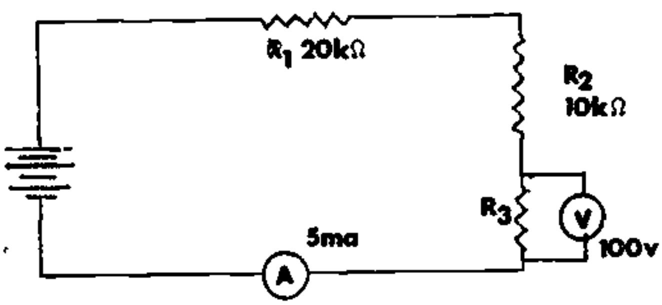
39. Solve the circuit for quantities indicated.



a. R_2 ______
b. I_{R2} ______
c. E_{R1} ______
d. E_{R3} ______
e. E_a ______
f. I_{R3} ______

(a. 5kΩ; b. 1 amp; c. 8kv; d. 2kv; e. 15kv; f. 1 amp)

40. Solve the circuit for quantities indicated.



a. I_T ______
b. R_T ______
c. E_{R1} ______
d. E_{R2} ______
e. I_{R3} ______
f. R_3 ______
g. E_a ______

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 40

a. 5ma

b. 50kΩ

c. 100v

d. 50v

e. 5ma

f. 20kΩ

g. 250v

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 22 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON II

The Ohm's Law Formula

The statement of Ohm's Law in the last lesson sets forth the relationship of current to voltage and resistance. This can be expressed much more briefly and conveniently in the form of an equation:

$$\text{Current (in amperes)} = \frac{\text{Voltage (in volts)}}{\text{Resistance (in ohms)}}$$

This equation can be reduced still further by use of the alphabetic symbols for voltage, current, and resistance; $I = \frac{E}{R}$. When using this formula, you will need to know the metric prefixes and powers of ten to keep your values straight.

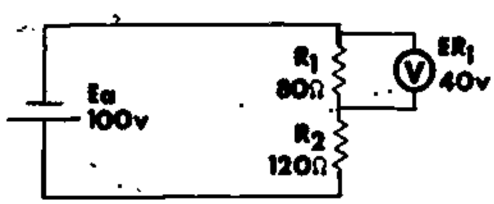
Here is an application of Ohm's Law to a circuit:

To find the effective AC current in this circuit, substitute values in the Ohm's Law formula. $I = \frac{E}{R} = \frac{12v}{6\Omega} = 2a$. If the resistance had been 6kΩ, the solution would have been

$$I = \frac{E}{R} = \frac{12v}{6k\Omega} = I = \frac{12v}{6 \times 10^3\Omega} = 2 \times 10^{-3}a \text{ or } 2ma.$$

The Ohm's Law equation can be manipulated to find any one value if the other two are known. For example, to find resistance when current and voltage are known, the formula transposes to $R = \frac{E}{I}$. Solving for voltage yields $E = IR$.

The Ohm's Law formula can be applied to a part of a circuit as well as to a complete circuit. You must always be careful to use the correct set of values in solving a problem, for it is easy to slip and use applied voltage instead of the voltage drop across one particular resistor. Here is an illustration which may help clear this up:

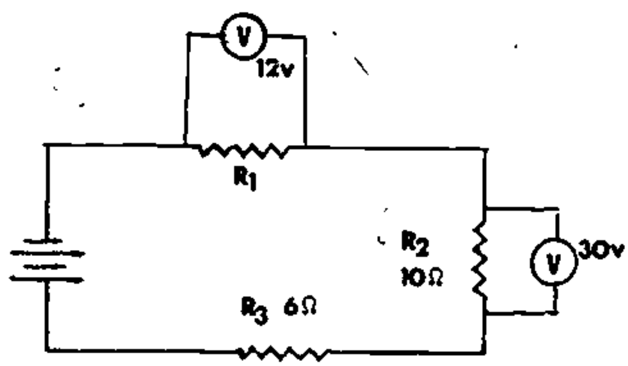


Find circuit current! Current can be found more than one way, but the fastest method is to use E_{R1} and R1 like this: $I = \frac{E_{R1}}{R1} = \frac{40v}{80\Omega} = \frac{1}{2}$ a. If applied voltage is used, the total resistance will give the correct

answer, but using applied voltage with the value of R1 would give 2.5a, a totally wrong answer. You could have added R1 and R2 to find total resistance (200 Ω) and then divided ($I = \frac{E_a}{R_T} = \frac{100v}{200\Omega} = .5a$), again the correct answer.

By using the Ohm's Law equation in conjunction with the rules for series circuits, you can find a great deal about a circuit from relatively little given information.

To illustrate the last statement, the circuit below can be solved for voltages, resistances, and current.

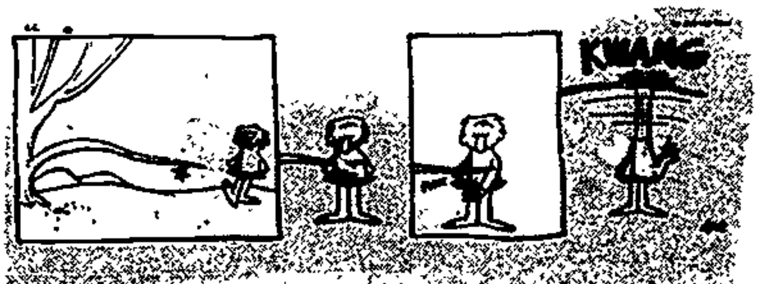


The first step here is to find a part of the circuit which has two values given so that the third may be found. In this circuit, the resistance of R2 and the voltage across it are both shown, so we can start there.

$I_{R2} = \frac{E_{R2}}{R2} = \frac{30v}{10\Omega} = 3a$. This is a series circuit, so the current is 3 a in all parts of it. The voltage across R3 is then 18 v ($E_{R3} = I \times R3 = 3a \times 6\Omega = 18v$). The resistance of R1 is 4 Ω ($\frac{12v}{3a} = 4\Omega$). Total voltage can be found by adding E_{R1}, E_{R2}, and E_{R3}, and total resistance can be found by adding the resistance values or by $\frac{E_s}{I} = R_T$.

Of course, the order of steps after current has been found can be changed, and there are several ways to get total voltage or total resistance. Some problems may require several steps before you find the solution, so don't give up too easily.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.



If you don't know what it does don't fool with it!

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BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE FIVE
LESSON III

Power

Study Booklet

ERIC

OVERVIEW

LESSON III

Power

In this lesson, you will study and learn about the following:

- -definition of power
- -quantity of power
- -unit of measure
- -power formula
- -practical applications of power formula

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

ERIC

LIST OF STUDY RESOURCES

LESSON III

Power

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-Ia "Basic Electricity, Direct Current." _Fundamentals of Electronics_. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

You may study whatever learning materials you feel are necessary to answer the questions in the Lesson Progress Check. All your answers must be correct before you can go to Lesson IV. Remember, your instructor is available at all times for any assistance you may need.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON III

Power

Introduction

So far, we have discussed current, voltage, and resistance, and how they are related. There is another electrical quantity you have to learn about - power.

You recall from the module on resistance that resistors are rated for the power they can dissipate as well as for their ohmic values. To make use of this rating, you must understand what power is.

Definition

Power is the rate of doing work, that is, the amount of work done per unit of time. As an example, think of two men shoveling equal piles of sand into trucks. One of the men can complete his task in 15 minutes. The other man is stronger and can finish his job in 5. Both do the same amount of work, but the man who finishes first has used more power.

Similarly, if you have two electrical circuits with identical resistances, but different applied voltages, the circuit with the stronger voltage will have a greater current flow (electrons moving faster). This is another way of saying more work is done in a given time; therefore, the circuit with the greater voltage will expend more power. Power is the amount of work divided by the time it takes to do the work. Stated in symbols, $P = \frac{W}{T}$, where P is power, W is work, and T stands for time.

Amount of Power

When the control on an electric iron is turned off, no current can flow through its resistance, and no power is present. As you change the control to a warm setting, current flows through the resistance and the iron heats.

When you turn the dial to a hot setting, more electrons move through the circuit over a period of time, so more power is expended and the iron gets hotter. More power always produces more heat.

Unit of Measure

Power is measured in watts and the symbol is W. (Upper or lower

case W's are used.) Note that W may mean either work or watts. Appliances and light bulbs are rated in watts. You know that a 150 W bulb burns more brightly and gives off more heat than a 40 W bulb. The 150 W lamp dissipates more power (has a greater current flow) because it has lower resistance than the 40 W bulb. This is true for all light bulbs and appliances when they are operated at the correct voltage.

Power Formula

Occasionally it will be necessary to know how much power is being used in a circuit or how much power a component is dissipating. For example, if a resistor rated at 20 watts is used in a circuit where it dissipates 60 watts, it will very quickly burn out. (Remember, resistors are rated according to how much power they are capable of dissipating.)

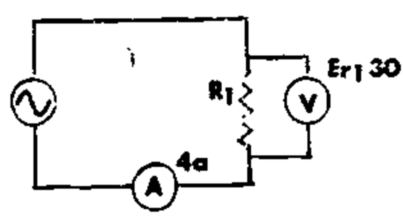
The amount of power in a circuit depends on how much current flows and upon how much voltage is applied. Many years ago, scientists found that the power (in watts) equals the voltage (in volts) times the current (in amperes). Written in symbols, this is P = EI. Be careful to use the correct voltage and current for the power you want to find. Total power (P_T) can be found using total current and applied voltage; power dissipated in one component can be found from the current through that component and the voltage across it.

The formula P = EI expresses these relations:

Voltage and power are directly proportional (I constant).

Current and power are directly proportional (E constant).

In this example, the power dissipated in R1 can be found by using the power formula:



$P_{R1} = E_{R1} \times I_{R1}$

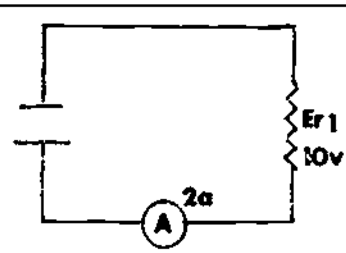
$P_{R1} = 30v \times 4a$

$P_{R1} = 120w$

Use the formula P = EI, Ohm's Law, and the rules for series circuits to find the values asked for in the following problems.

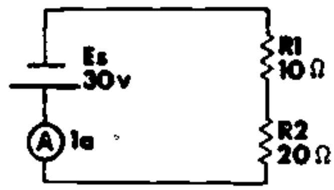
---

a.



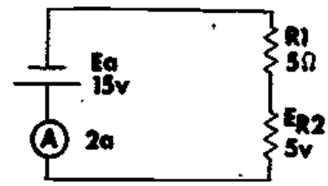
$P_{R1} =$ ______

b.



P_T = ______

c.



P_{R2} = ______

(a. 20w; b. 30w; c. 10w)

Another Power Formula

A second formula for finding power is $P = I^2R$. This version of the power formula permits solving for power when current and resistance are known. Actually this formula is a combination of the first power formula and Ohm's Law where the E in P = EI is replaced by IR.

By taking this equation $P = I^2R$ and substituting for I, $I = \frac{E}{R}$. Therefore:

$$P = I^2R$$

$$P = I \times I \times R = \frac{E}{R} \times \frac{E}{R} \times R$$

$$P = \frac{E^2}{R^2} R$$

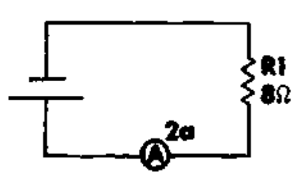
$$P = \frac{E^2}{R^{\cancel{2}}} \cancel{R}$$

$$P = \frac{E^2}{R}$$

Solve the following problems. Don't forget to square the current and voltage values when indicated by the formulas.

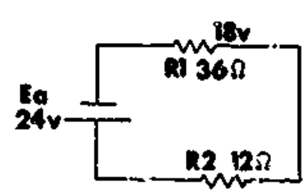
Use $P = I^2R$

a.



Use $P_{R2} = \frac{E_{R2}^{\ 2}}{R2}$

b.



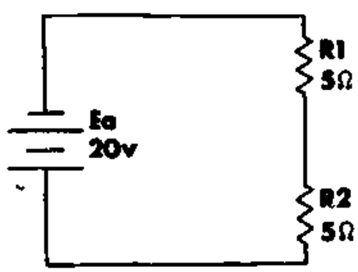
(a. 32 W; b. 3 W)

ERIC

Solving Circuits for Power

By combining the power formula and Ohm's Law with the rules for series circuits, a lot of information can be discovered from few known values.

For example, in the following problem total power can be found from the information given.



First, the total resistance can be found for $R_T = R1 + R2$, or $R_T = 10\Omega$. Current then can be found from Ohm's Law:

$$I = \frac{E_a}{R_T}$$

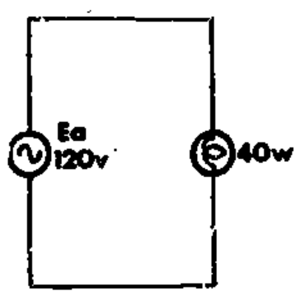
$$I = \frac{20v}{10\Omega}$$

$$I = 2a$$

Then using the formula $P = EI$, total power is shown to be 20v x 2a or 40w.

You can also transpose the power formula to find other values as in this problem.

Find the current required for a lamp rated at 40w and 120v.



$$P = E \times I$$

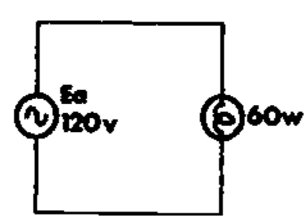
$$40w = 120v \times I$$

$$40w \div 120v = I$$

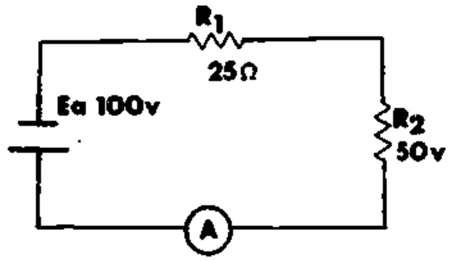
$$I = 1/3a$$

Practice these problems and check your answers with answers on the next page.

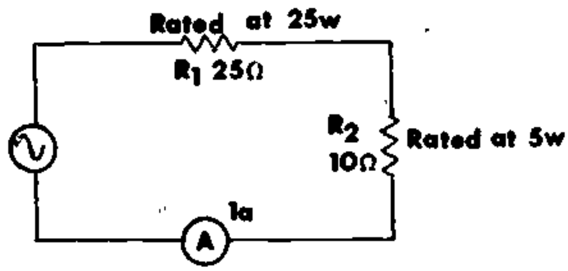
a.



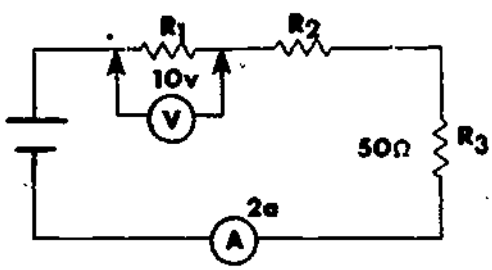
How much current will the lamp draw?

b. 

Solve for total power. ______

c. 

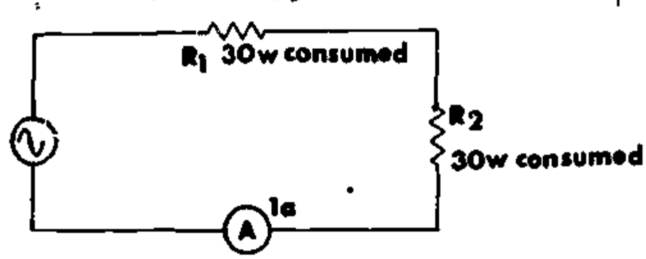
Which resistor or resistors will burn out? ______

d. 

P_{R1} = ______

P_{R3} = ______

Solve for P_{R1} and P_{R3}.

e. 

Solve for R_T. ______

COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN BELOW:

a. 0.5 amps

b. 200 w

c. R2

d. P_{R1} = 20 w

P_{R3} = 200 w

e. 60 Ω

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Power

TEST FRAMES ARE 7, 14, 20 AND 28. AS BEFORE, GO FIRST TO TEST FRAME 7 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. A concept which is necessary for working with electricity is power. Power is used to rate appliances such as toasters, irons, lamps, etc., as to the load they place upon a source; to rate the source as to how much electricity it can supply, and to rate components as to how much energy they can safely convert.

   The power rating of a component may tell how much:

   ___ a. power it can convert.
   ___ b. power it can supply.
   ___ c. load it places on the source.
   ___ d. all of the above.

- -

(d) all of the above

2. Power (P) is defined as work per unit of time and is found by dividing the work (W) performed by the time (T) in seconds required to do the work.

   Define power. ______________________________

- -

(Power is work per unit of time.)

3. Write the equation for power in terms of work and time.

   ____

- -

($P = \frac{W}{T}$)

4. Two men are waxing identical cars. Man A finishes his car in 15 minutes, while man B takes 25 minutes to do his.

Which man expended the most power in waxing his car?

(A)

5. In applying this formula to electricity, we may define power as the rate of converting electrical energy to another form of energy. In our illustrations, the resistors convert electricity to heat, and power can be determined by measuring the amount of heat produced in a given time.

It has been determined experimentally that the amount of heat produced by a resistor is directly proportional to resistance, the square of the current, and time. As an equation this is written:

$$\text{Amount of Heat} = I^2RT$$

State the relationship between heat, current, resistance, and time as applied to a resistor in a circuit. ______________

(Heat is directly proportional to the resistance, the square of the current, and time.)

6. Electrical power is defined as ______________

(rate of converting electrical energy to another form of energy.)

7. The amount of power in a circuit:

___ a. is like the energy available to do work.
___ b. is like the energy used by a man waxing his car in 30 minutes.
___ c. is the capability of the circuit to do work.
___ d. is the rate of converting electrical energy to another form of energy.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 7

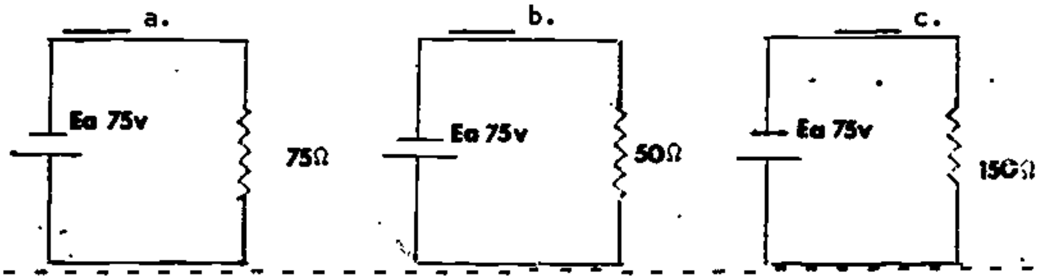
b. is like the energy used by a man waxing his car in 30 minutes.

d. is the rate of converting electrical energy to another form of energy.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 14. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 7 AGAIN.

8. The more electrons moving in a circuit, the more power the circuit will consume.

Select the circuit which consumes the greatest amount of power.



(b)

9. Recall that resistors have a power or wattage rating.

Select the units of power.

___ a. amps (a)
___ b. ohms (Ω)
___ c. watts (W)
___ d. volts (v)

(c) watts (W)

10. Starting from the basic equation $P = \frac{W}{T}$, and substituting I^2RT for W (work), we can derive an equation for power in electrical terms:

$$P \text{ (in watts)} = \frac{W}{T} = \frac{I^2R\cancel{T}}{\cancel{T}} = I^2R$$

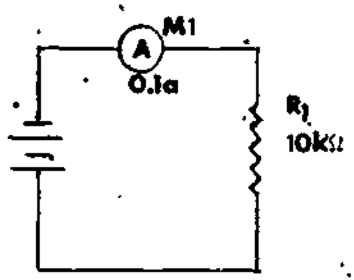
Note, that W is used for both watts and work, so be careful when W is used.

State the equation for power in terms of current and esistance.

____

($P = I^2R$)

11. Find the power expended by R1 in this circuit.



P1 = ____ watts

---

(100)

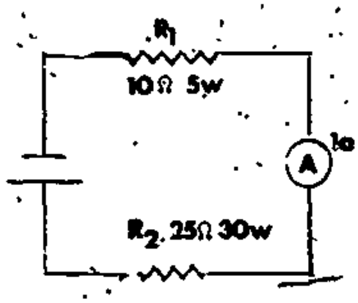
12. The power expended in a resistor or resistance is known as true power or power which actually does work.

A lamp uses what type of power?

___ a. reactive power in VAR's.
___ b. true power in watts.
___ c. apparent power in VA's.

(b) true power in watts

13. State which resistor will burn out.



______

(R1)

14. True power:

___ a. may be defined as power which has a true and constant energy value.

___ b. is used when a waffle iron, toaster, or a lamp operates.

___ c. may be defined as power that actually does work and/or is dissipated in heat.

___ d. is present in a circuit in which the switch is open.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 14

b. Is used when a waffle iron, toaster, or a lamp operates.

c. may be defined as power that actually does work and/or is dissipated in heat.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO ON TO TEST FRAME 20. OTHERWISE, GO BACK TO FRAME 8 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 14 AGAIN.

15. Another statement for power in electrical terms can be derived from $P = I^2R$ and Ohm's Law. This equation is useful when voltage and resistance are the known values.

From $P = I^2R = I \times I \times R$

substitute $\frac{E}{R}$ for $I = \frac{E}{R} \times \frac{E}{R} \times R =$

$$P = \frac{E^2}{R^2} \times R$$

$$= \frac{E^2}{R^{\cancel{2}}} \cancel{R}$$

so, $P = \frac{E^2}{R}$

Write the equation for power in terms of voltage and resistance.

____

($P = \frac{E^2}{R}$)

16. Find the power dissipated by a 300-ohm resistor connected across a 60 volt source. ______________

($P = \frac{E^2}{R} = \frac{(60)^2}{300} = \frac{3600}{300} = 12\text{w}$)

83

17. One more expression may be developed by a similar method, using $R = E/I$ for the substitution.

From $P = I^2R$ and $R = \frac{E}{I}$, substitute $\frac{E}{I}$ for R.

Then $P = I^{\cancel{2}}\frac{E}{\cancel{I}}$

so, $P = EI$

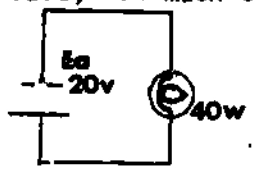
Write the equation which solves for power when voltage and current are known. ____________

(P = EI)

18. Given that E_s is 30v and I_T is 5ma, find P_T. ____________

(150 mw)

19. In this circuit, how much current will the lamp draw?



____

(2 amps)

20. Check the circuit relationships that are directly proportional:

___ a. current and resistance.

___ b. current and power.

___ c. current and voltage.

___ d. voltage and power.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 20

b. current and power.

c. current and voltage.

d. voltage and power.

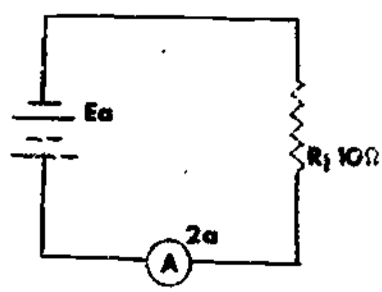
IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO ON TO TEST FRAME 28. OTHERWISE, GO BACK TO FRAME 15 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 20 AGAIN.

21. The total power consumed in a series circuit is the sum of the power consumed in each individual load device.

Write the equation for total power dissipated in a series circuit consisting of four resistors when the power consumed in each load in the circuit is known: ______________

($P_T = P_{R1} + P_{R2} + P_{R3} + P_{R4}$)

22. Using any one of the preceding equations as necessary, find the power dissipated in the following circuit.

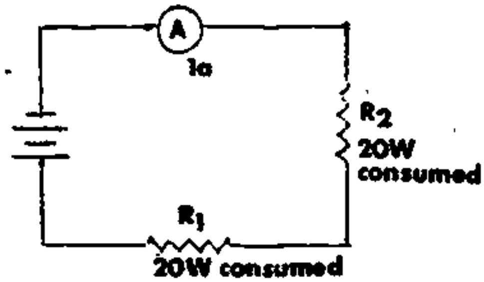


P_T = ____

(40w)

85

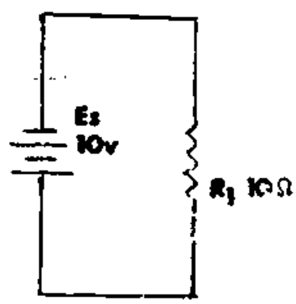
23. Solve.



R_T = ____

(40 ohms)

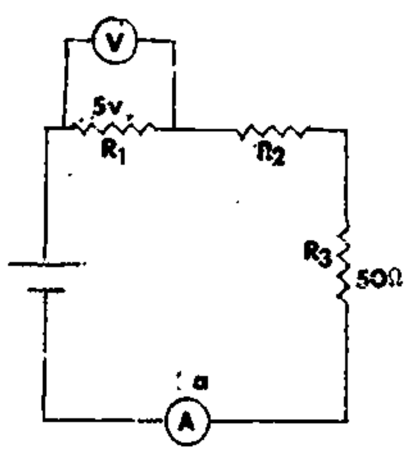
24. Find P_T.



P_T = ____

(P_T = 10w)

25. Solve.



P_{R1}= ____

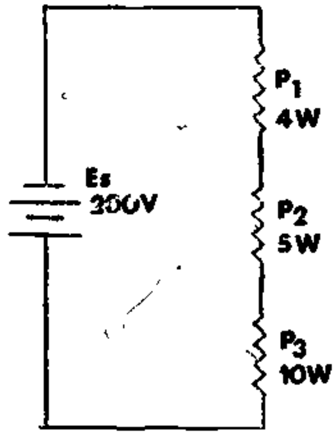
P_{R3} = ____

(P_{R1} = 10w; P_{R3} = 200w)

26. In a circuit which carries 3 amperes and has a 30-volt source, what is the total power dissipated?

(90w)

27. Fine P_T.



(19w)

87

28. For the following circuit, find all values of voltage, current, resistance, and power which are not given.

Find:

I ______

$R1$ ______

P_{R1} ______

E_{R2} ______

P_{R2} ______

$R3$ ______

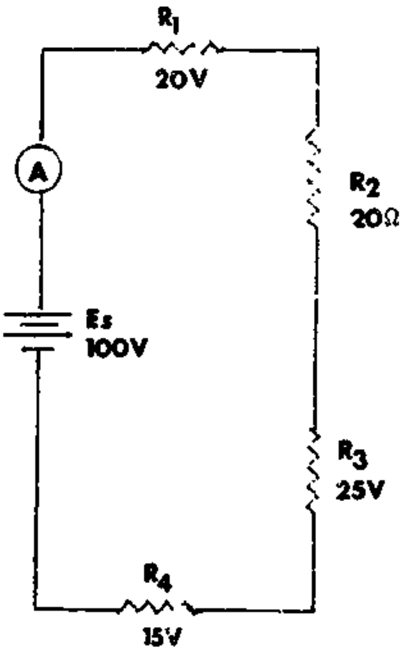
P_{R3} ______

$R4$ ______

P_{R4} ______

P_T ______

R_T ______



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 28

$I = 2a$

$R1 = 10\Omega$

$P_{R1} = 40w$

$E_{R2} = 40v$

$P_{R2} = 80w$

$R3 = 12.5\Omega$

$P_{R3} = 50w$

$R4 = 7.5\Omega$

$P_{R4} = 30w$

$R_T = 50\Omega$

$P_T = 200w$

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 21 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON III

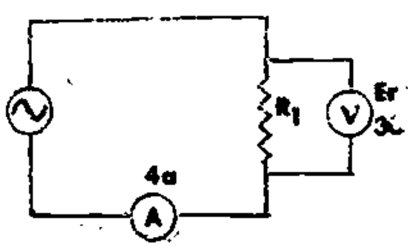
Power

Another electrical quantity you must learn about is power, the rate of doing work. In other words, power is the amount of work done per unit of time. Two electrical circuits with identical resistances but different applied voltages will have different amounts of current flow. The circuit with the greater current will be dissipating more power, for more work (in the form of moving electrons) is being done each second. Power, defined by using symbols in a mathematical approach, is $P = \frac{W}{T}$, where P is power, W is work, and T is time.

Power in a circuit is usually converted to heat and dissipated into the air. The greater the power in a circuit, the greater the heat dissipated. The unit of measurement for power is the watt, and its symbol is either upper or lower case W.

You remember that resistors are rated according to the amount of power they are able to handle. You may need to calculate the power in a circuit or in a component to be sure that it is operating within its rating; a resistor rated at 20 watts will very quickly burn out if it is operated at 60 watts, for example.

Electrical power can be shown as the product of voltage and current, but you must always be careful to use the correct voltages and currents. Total power (P_T) can be found from total current and applied voltage, but the power dissipated in one component can be found only if you use the voltage across the component and the current through it. The power dissipated by R1 in the following diagram is:



$P_{R1} = EI$

$P_{R1} = 30v \times 4a$

$P_{R1} = 120w$

Another formula for finding power can be derived by substituting IR for E in the formula to yield $P = I^2R$. This formula is useful when current and resistance are known.

Combining the power formulas with Ohm's Law and the series circuits rules allows a lot of information to be found from relatively little known data.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


POOR SHOT–
TRASH
POOR
HOUSEKEEPING

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE FIVE
LESSON IV

Internal Resistance

Study Booklet

OVERVIEW
LESSON IV

Internal Resistance

In this lesson you will study and learn about the following:

- what internal resistance is
- how internal resistance affects current

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

ERIC

LIST OF STUDY RESOURCES

LESSON IV

Internal Resistance

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

Remember, you may study whatever learning materials you feel are necessary to answer the questions in the Lesson Progress Check. All your answers must be correct before you can go to Lesson V. Your Instructor is available at all times for any assistance you may need.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

ERIC

NARRATIVE
LESSON IV

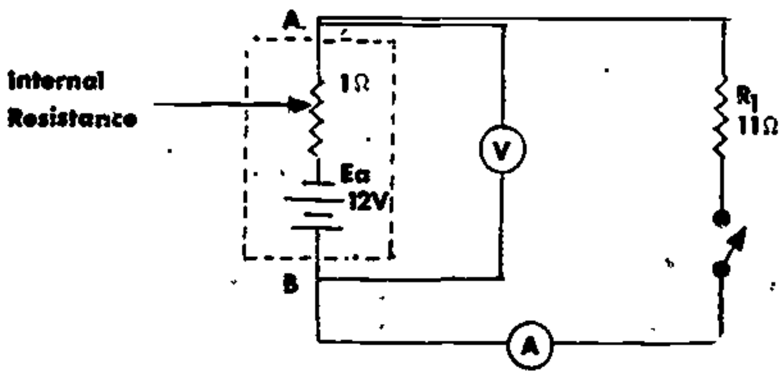
Internal Resistance

Definition

When you learned about resistance, your attention was focused on the resistance of the load in a circuit, but there is another very important resistance in any operating circuit. This is the resistance inside the source. All sources - batteries, generators, or whatever - have resistances inside them which oppose the movement of electrons.

In a battery, the chemicals which separate the electrons from their atoms also offer resistance to their movement. In a generator, the wires in which EMF is generated also have a certain amount of resistance. This opposition is called the internal resistance of the source.

Although you cannot see this resistance or measure it with an ohmmeter, you can determine its effect on a circuit. To help you do this, think of the internal resistance as being in series with the source. This resistance is usually shown schematically like the drawing below.



The dashed line indicates that the internal resistance is part of the source.

Let's see what this resistance does to a circuit, and why it is important to you. In the circuit shown above (notice open switch), a voltmeter placed on the battery terminals (points A and B) will indicate 12 volts. This is called the no-load voltage, for no load is connected to the battery and no current flows.

If you now close the switch, a current of 1 ampere will flow in the circuit, and the voltmeter reading will drop to 11 volts. This decrease in the battery's terminal voltage is due to the voltage dropped by the battery's internal resistance. From this you can conclude that the internal resistance of a source will reduce the output voltage when current is flowing.

Using Ohm's Law and the total voltage law (sometimes called Kirchhoff's Voltage Law), you can find any of the values in a circuit like this one. For example, you can find the value of the internal resistance of the battery with only the meters shown in the diagram.

The steps to follow are:

1. Measure the no-load voltage. This is the actual value of the battery EMF, for there is no current flow and therefore no voltage drop across the internal resistance of the battery. (12v)
2. Energize the circuit and measure the terminal voltage of the source (11v).
3. Subtract the load terminal voltage from the no-load terminal voltage. This tells you how much voltage is dropped by the internal resistance. (12v - 11v = 1v)
4. Measure current flow in the circuit. (1a)
5. Divide the voltage drop of the internal resistance by the circuit current. (1v/1a = 1Ω; from the Ohm's Law variation R = E/I)

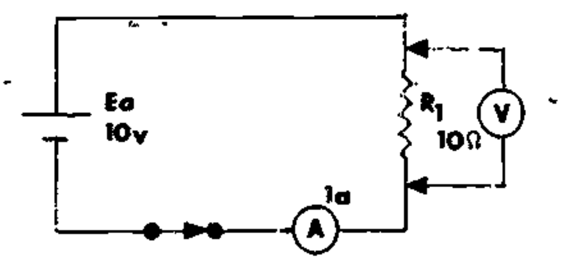
Now try this on a circuit of your own. Read the voltage between the terminals of one of your dry cells. This should be about 1.5v. Connect a light bulb to the cell and measure the terminal voltage again. The current flow through the cell's internal resistance should cause the output of the cell to drop to about 1.45v. As a dry cell ages, its internal resistance increases. This indicates when to throw it away. When the dry cell's voltage drops too much under normal load, its useful life is over.

The voltage drop across the internal resistance of the cells in the circuits you are using is insignificant, but in circuits with large currents, the losses can be important.

How Internal Resistance Affects Current

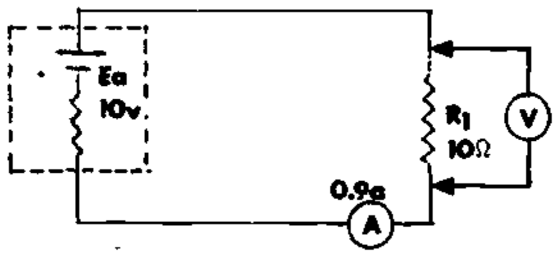
In most cases the effects of internal resistance in a circuit are negligible, but a large internal resistance will severely limit the amount of current flow.

In this circuit, the internal resistance is so small it can be ignored, and all the values work out well within the tolerance of our meters.



ERIC

If we replace the source with one which has a higher internal resistance, it will change the circuit, and we might get readings like these:



The latter readings differ considerably from those in the first case. If we accidentally connect a straight piece of wire across the terminals of a battery, the only resistance in the circuit is internal resistance, and the entire EMF is dropped within the source. Of course, this will very quickly destroy the source unless it is protected in some way.

In the rest of the course, you will ignore the effects of the internal resistance of a source unless it is specifically included in the problem or discussion. It is important that you know about internal resistance so you can understand what occurs in electrical circuits, but internal resistance will not usually be large enough to make a significant difference in your calculations.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON IV

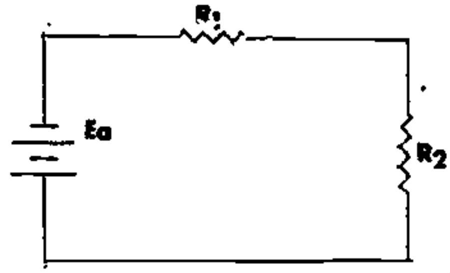
Internal Resistance

TEST FRAMES ARE 6, AND 14. GO FIRST TO TEST FRAME 6 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Recall the effects of series resistance on voltage drop throughout a circuit.

   Increasing the ohmic value of R1 would have what effect on the voltage drop across R2? ____________



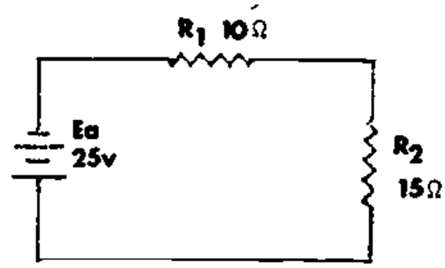
- -

(E_{R2} would decrease)

---

2. As you can see, increasing the value of a series resistor decreases the voltage to the other components in the circuit.

   Increasing R1 to 15Ω would result in the voltage drop across R2 decreasing by _____ volts.



- -

(2.5v)

3. In your own words, describe the effect of increasing the value of a series resistor upon the voltage drop across the other components in the circuit.

____

____

(The voltage drops across the other compon nts will decrease)

4. Up to this point, a source has been considered to be a fixed or constant voltage. In a practical source, however, there is a certain amount of opposition to current flow which will cause the output (or terminal) voltage of the source to vary as current flow in the circuit varies. This opposition is called the internal resistance (symbol R_i) of the source, and is present in all circuits.

In your own words, define internal resistance.

____

____

(the opposition to current flow that is present inside a source)

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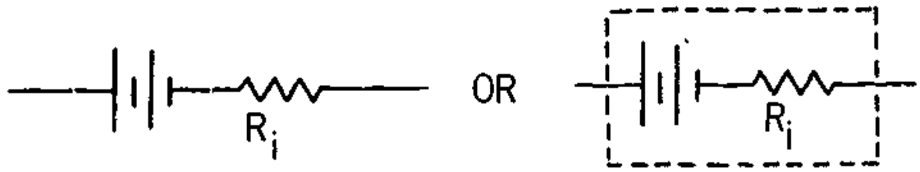
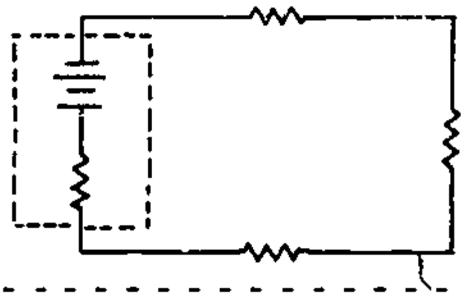
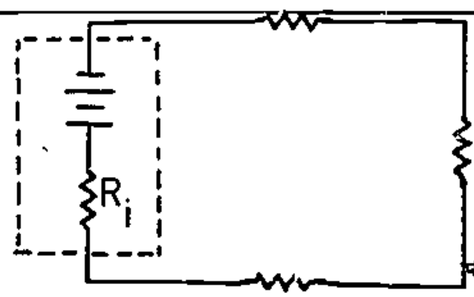
5. When shown in a schematic diagram, this internal resistance is represented by a series resistor, and it may be shown inside a dashed line box with the source



Label the internal resistance.





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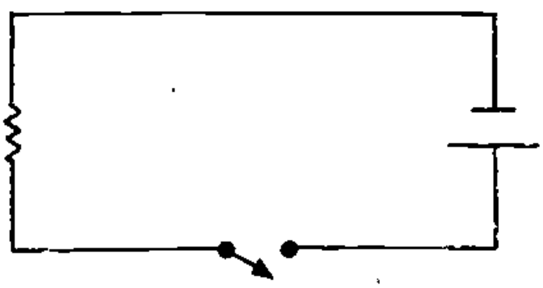
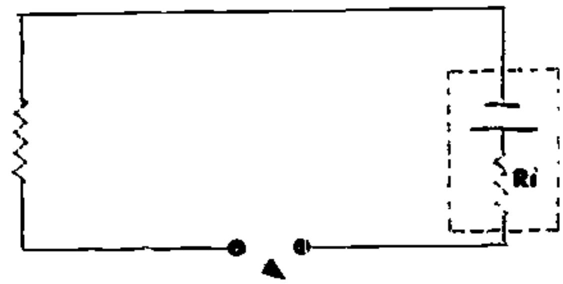
6. Redraw this schematic to include a representation of internal resistance.



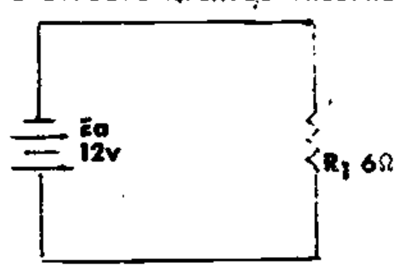
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 6



IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 14. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 6 AGAIN.

7. How does this internal resistance affect the circuit? First look at a circuit without internal resistance.

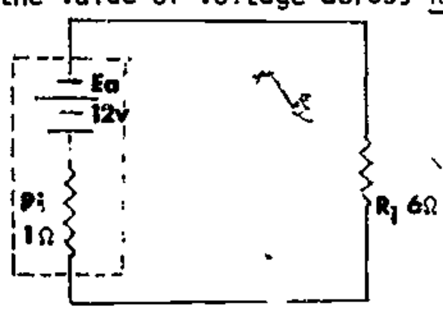


What is the voltage drop across R1? ____________ volts

(12v)

8. Now the same circuit with 1 ohm of internal resistance.

What is the value of voltage across R1? _____ volts.



$(I = \frac{E_a}{R_T} = \frac{12}{7} = 1.7a, \quad E_{R1} = (I)(R1) = 1.7a)(6\Omega) = 10.2v)$

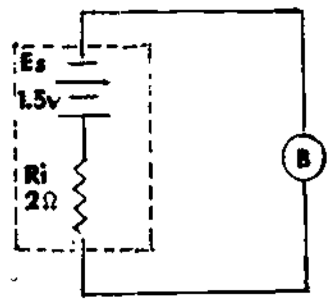
9. Since the internal resistance is inside the source, what is the battery's terminal voltage (voltage available to the load) in frame 8? ________ volts.

(10.2v)

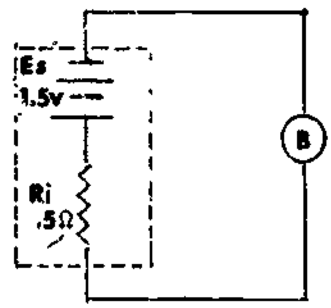
10. This internal resistance is often so small in relation to the current flow in the circuit that it can be ignored, but it is always present and can be an important factor in some circuits.

For example, the motor (B) requires 500ma at 1.2v to operate and has a resistance of 2.4Ω.

Example 1: Using a penlight cell as shown, the motor will not operate, for its 2.4 ohms in series with the 2 ohm internal resistance of the cell will permit a current flow of only 340ma and the terminal voltage of the cell is only
1.5 - (340ma x 2Ω) = 0.82v



Example 2: Replacing the penlight cell with a larger cell which has only 1/2-ohm internal resistance and solving the circuit, there is 2.9 (2.4 + 0.5) ohms opposition to current flow, and the current will be
1.5v/2.9Ω = 517ma



and the cell terminal voltage will be 1.5v - (517ma x .5Ω) or 1.243v which is enough to operate the motor.

How does the internal resistance of a source affect the source terminal voltage? ____________________

(The internal resistance of a source decreases the terminal voltage.)

11. Since the internal resistance is inside the source, it cannot be measured with an ohmmeter.

Internal resistance can be determined by:

___ a. ohmmeter reading.
___ b. calculation, using Ohm's Law.
___ c. current readings.
___ d. voltmeter readings.

(b) calculation, using Ohm's Law

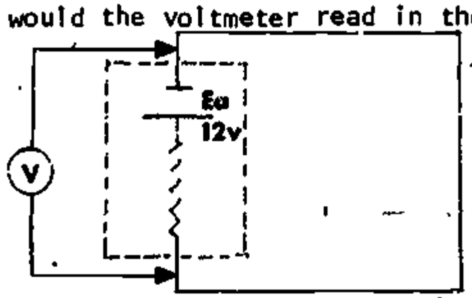
12. Check the phrase that best defines internal resistance.

___ a. opposition that limits current flow and can be measured with an ohmmeter.
___ b. opposition that limits current flow and occurs within a wire.
___ c. opposition that limits current flow and occurs within the source.

(c) opposition that limits current flow and occurs within the source

13. If a wire is placed directly across the output terminals of a cell, the entire cell voltage will be dropped across the internal resistance of the cell.

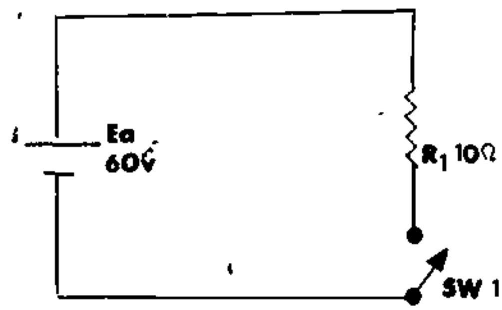
What would the voltmeter read in the illustration below?



______

(0 volts)

14. Assume the internal $\underline{R}$ is 5Ω. When $\underline{SW1}$ is closed, what will E_{R1} be? ________ volts.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 14

40

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO THE NEXT FRAME. OTHERWISE, GO BACK TO FRAME 7 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 14 AGAIN.

15. It is important that you be aware of the existence of internal resistance; however, for our purposes in this course, unless an internal resistance is indicated, we will idealize circuit quantities, and make mathematical calculations as if internal resistance did not exist.

(No response required.)

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

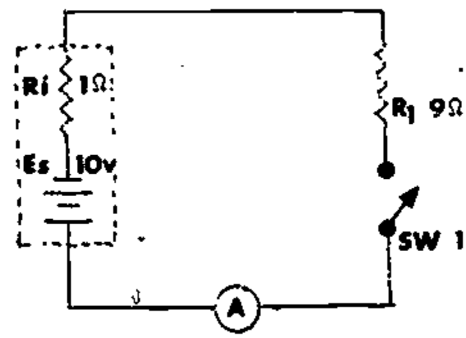
SUMMARY
LESSON IV.

Internal Resistance

A resistance we have not yet discussed is the internal resistance of a source; that is, the opposition to current flow which is present to some degree inside every source of voltage. You cannot measure this resistance with an ohmmeter, but it will have an effect on a circuit. To explain how the internal resistance affects a circuit, think of it as a series resistance which is inside the battery itself. This is usually shown on a schematic like this:

Internal resistance = 1Ω

E_s = 10v



The dashed line indicates the resistance and the source are in the same physical package.

The internal resistance of the source drops some of the source voltage whenever current flows in the circuit, and effectively reduces the output of the source if the current is high or the internal resistance is large. Refer again to the circuit above. If a voltage reading of the source is taken with the switch open, the meter will indicate 10v, for there will be no voltage drop across the internal resistance when no current is flowing. If the switch is closed and the voltmeter reading taken again, the meter will then read 9v due to the voltage drop across the internal resistance.

You can find the value of the internal resistance in a circuit by using information you already have. The steps are:

1. Measure the no-load voltage. This is the voltage at the source terminals when no current flows in the circuit.
2. Energize the circuit and measure the source terminal voltage under load conditions.
3. Find the difference between no-load and load voltages. This difference is the voltage drop across the internal resistance.
4. Measure current flow in the circuit.
5. From the Ohm's Law derivative R = E/I, find the value of the internal resistance.

Because the internal resistance of a dry cell increases as it ages, you can use this as an indicator of its condition. A good battery will read near its rated voltage under normal load, but a poor one will read much below its rated voltage and should be discarded.

The internal resistance of a source explains why the output voltage of a battery drops to 0 when a direct short occurs between its

terminals; the entire EMF is dropped across the internal resistance.

Because the voltage drop across the internal resistance is usually negligible, you will be able to ignore its effect in the problems you are given in this course.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE FIVE

LESSON V

Troubleshooting Series Circuits

ERIC

OVERVIEW
LESSON V

Troubleshooting Series Circuits

In this lesson you will study and learn about the following:

- short circuits (direct shorts and partial shorts)
- fuses
- open circuits
- locating shorts
- locating opens
- defective switches or fuses

Each of the above topics will be discussed in the order listed. As you proceed through this lesson, observe and follow directions carefully.

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

ERIC

LIST OF STUDY RESOURCES
LESSON V

Troubleshooting Series Circuits

To learn the material in this lesson, you have the option of choosing, according to your experience and your preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/Slide Presentation - "Use of the Multimeter To Find Opens and Shorts."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME. UPON COMPLETION OF THIS LESSON YOU SHOULD ASK YOUR INSTRUCTOR FOR THE MODULE TEST COVERING ALL THE LESSONS IN THIS BOOKLET. YOU MAY REVIEW PREVIOUS LESSONS IF YOU WISH.

NARRATIVE
LESSON V

Troubleshooting Series Circuits

Introduction

Whenever something goes wrong with your equipment, you will be expected to find out what is wrong with it and eliminate the trouble. How well and how quickly you do this will determine what other people think of your work and will have some effect on your advancement in rating.

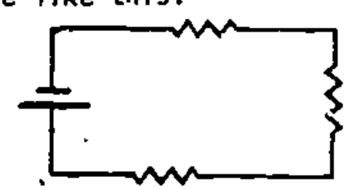
There are two kinds of circuit problems that cause most of the troubles you will run into. These are <u>short circuits</u> and <u>open circuits</u>.

Short Circuits

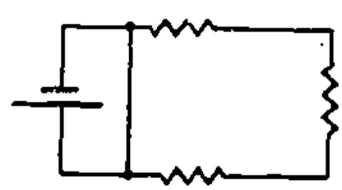
A short circuit is a current path which should not exist. A short circuit always reduces the resistance in a circuit and increases circuit current. Some common causes of short circuits are broken or cut insulation on wires; loose tools, solder, pieces of wire, etc., left on (or in) equipment; or dirt, salt water, filings, etc., around connection points and terminals.

Direct Shorts

A <u>direct short circuit</u> or <u>direct short</u> occurs when a conducting material forms a path directly between the terminals of the source like this:



NORMAL CIRCUIT



SHORT CIRCUIT

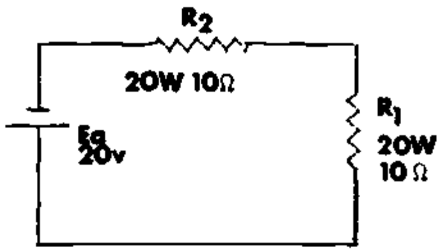
As the conductor has negligible resistance, a very large current will flow in the circuit, and either the source or the wiring will probably be damaged. The damage caused by this high current will usually open the circuit and stop all current flow.

The term <u>short circuit</u> originated from the idea that current bypasses the <u>normal load</u> in the circuit so that the current path is electrically shorter.

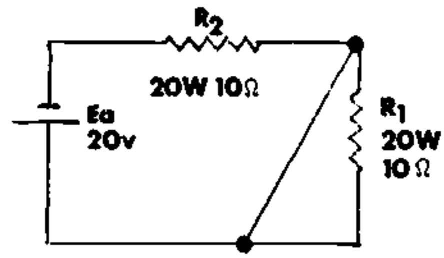
Partial Short

When a short circuit bypasses only part of the normal load in a circuit, it is called a <u>partial short</u>. A partial short reduces

current through the components which are bypassed, but it causes current to increase in all other parts of the circuit.



NORMAL



PARTIAL SHORT

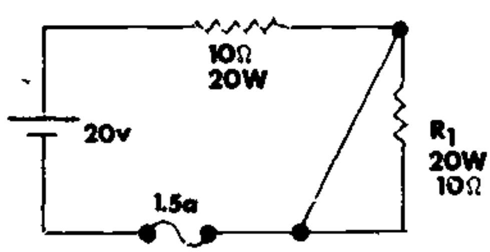
In the above circuit with the partial shor , there will be no voltage drop across <u>R1</u> because of the short, and the entire source voltage will be dropped across <u>R2</u>. Current in this circuit is 2 amperes instead of the 1 ampere current flow in the normal circuit. (You can work these out with Ohm's Law if you wish.) From the power formula, the power dissipated by <u>R2</u> will be 40 watts (P = EI = 20v x 2a = 40w). <u>R2</u> is rated for a maximum of 20 watts, so it will burn out.

<u>Fuses</u>

Partial shorts always cause an increase in current in a circuit and very frequently damage other components in a circuit. To reduce the amount of damage and the cost of repairs, circuits are usually protected by <u>fuses</u>. A fuse is a safety device designed to burn out when the current through it becomes too large. The value of resistance of a fuse is kept small enough so that it will not drop a significant amount of voltage in the circuit it protects.

Fuses are always connected in series with the devices they protect, and they are rated (in amperes) for the current they can carry without burning out or <u>blowing</u>. The schematic symbol for a fuse is ( ).

Here is a schematic diagram of a partially shorted circuit with a fuse to protect it.



ERIC

The normal current flow of 1 ampere will not burn out the fuse, for this is less than its 1.5-ampere rating. The increased current (2 amps) caused by the short across R1 is greater than the fuse rating and will cause the fuse to blow. This opens the circuit and prevents damage to R2 and the source.

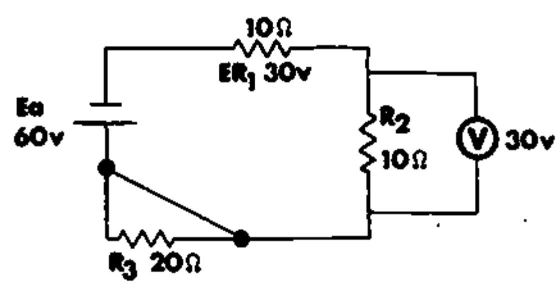
Open Circuits

An open circuit caused by a blown fuse or a bad component is a trouble condition which must be located and corrected. Of course, when you open a switch, you want an open circuit, and this kind of open is not a trouble condition.

Unwanted open circuits can occur because of dirt or corrosion on switch contacts, broken wires, or burned-out components.

Locating Shorts

Short circuits can be located with either a voltmeter or an ohmmeter. Using the voltmeter, any abnormal voltage indicates a fault in the circuit. In this circuit, reading 1/2 source voltage across R2 indicates that a trouble exists in the circuit, and since the voltage drop is greater than normal, the trouble is probably a short somewhere. Taking a voltage measurement across R1 will result in a 30-volt reading, indicating that no voltage is dropped across R3.



In the circuit above, a voltage reading of 0 volts across R3 indicates a short across R3.

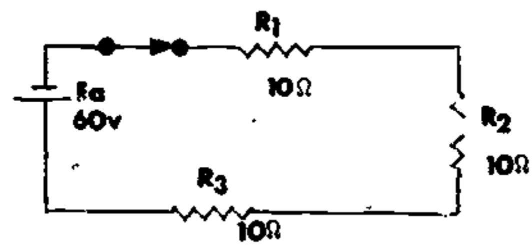
The first step in using an ohmmeter is always to be sure the circuit is de-energized, so disconnect the circuit from the source.

The resistance read across R1 will be about 20 ohms - a normal

condition. The ohmmeter will read 0 when placed across R2, telling you that R2 is shorted.

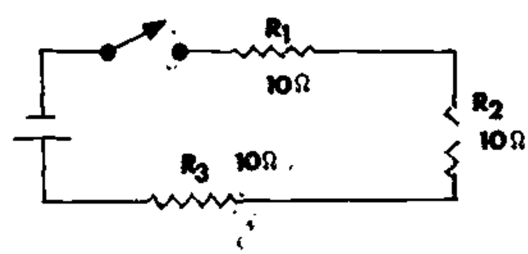
Locating Opens

You know that there is no current flow in a circuit when the current path is open, and that there is no voltage drop across a resistor when no current flows through it. It follows then that a voltmeter can be used to find an open circuit. With R2 open in this circuit, voltmeter readings across R1 and R3 will read 0 volts.



Across R2, however, the voltmeter will read the full 60v supplied by the source. Because the resistors R1 and R3 do not drop any of the source voltage, the full source voltage can be measured across the extremely high resistance of the open.

An ohmmeter also can be used to find an open circuit. Again, remember first to de-energize the circuit so that the ohmmeter will not be damaged. Next, take a resistance reading for each resistor. R1 and R3 should read 10 ohms each, but R2 will read infinity or open. Since R2 should also read 10 ohms, you know that R2 must be replaced.



Defective Switches or Fuses

An open circuit is often caused by a blown fuse or a bad switch. These defects are common open circuits, but such parts are overlooked so often that they need special mention. You locate these opens with a voltmeter in an energized circuit or an ohmmeter in a dead circuit. A good fuse or a closed switch in an energized circuit will show no voltage drop. In a de-energized circuit, a

good fuse will read 0 (or near 0) resistance, but a bad fuse will read infinite resistance.

NOW YOU MAY EITHER TAKE THE PROGRESS CHECK OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.

PROGRAMMED INSTRUCTION
LESSON V

Troubleshooting Series Circuits

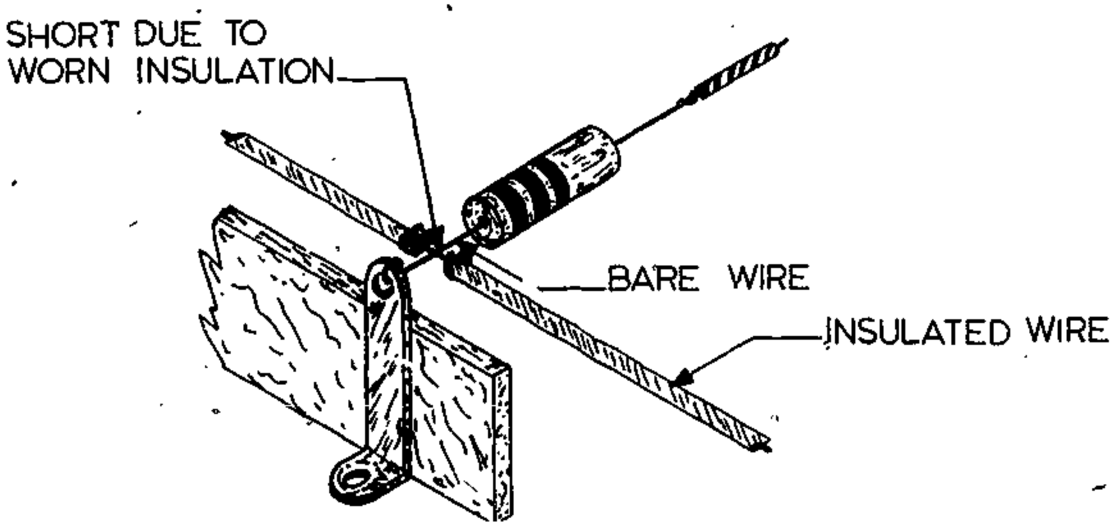
TEST FRAMES ARE 14, 18, 24, AND 25. GO FIRST TO TEST FRAME 14, AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. Now for a look at some of the things which can cause trouble in electrical circuits. A defect in a circuit which permits current to flow around all or part of the load is called a short circuit or short.

   An accidental path of low resistance is called a ______________ ______________ or ______________.

(short circuit, short)

2. Short circuits are commonly caused by frayed or broken insulation or wiring as shown by the illustration below.



   Describe a short circuit in your own words: ______________

(an abnormal current path bypassing all or part of the load)

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3. Since current will take the path of least resistance, a short provides a bypass around the component shorted out.

   Select the path current will take.

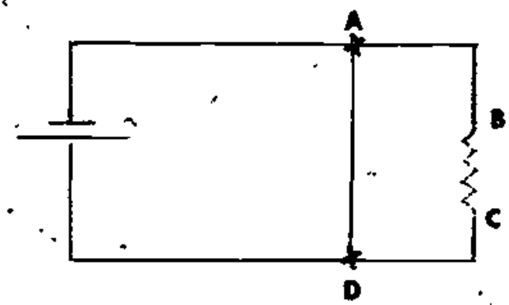
   ___ a. A to B

   ___ b. A to C

   ___ c. A to D

   ___ d. B to C

   ___ e. C to D

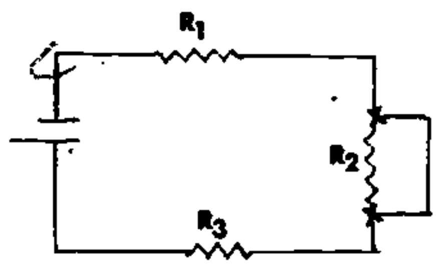


(c) A to D

---

4. Since current flows through a short instead of the component, there can be no voltage drop across the component shorted out.

   Which resistor will have no voltage drop across it?



   ___ a. R1
   ___ b. R2
   ___ c. R3

(b) R2

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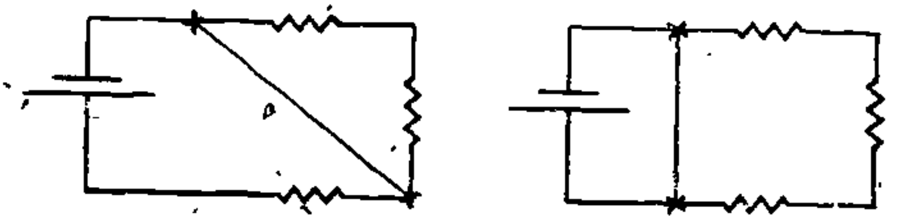
5. A short is called a direct short when it shorts the battery terminals.

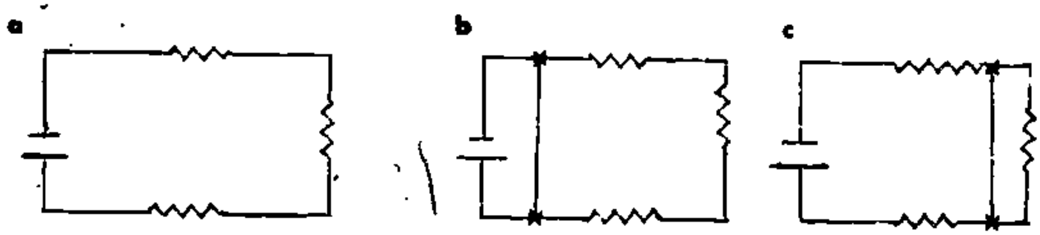
Which schematic shows a direct short?



(b)

6. A partial short is a short across only part of the circuit.

Select the illustration showing a partial short.



(c)

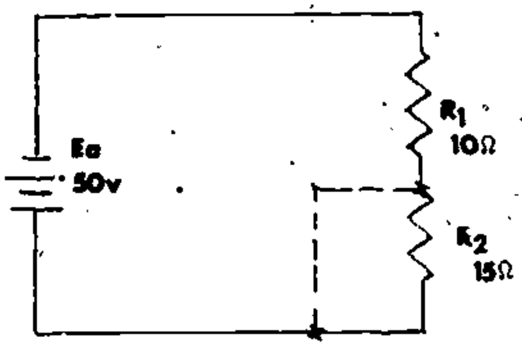
7. A short will cause the circuit resistance to decrease.

A short will cause circuit current to:

___ a. decrease
___ b. increase
___ c. remain the same

(b) increase

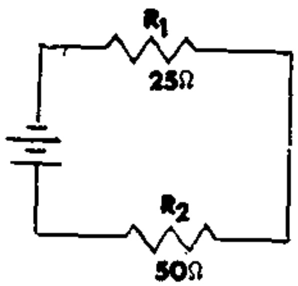
8. Now let's look at a circuit with only part of the load shorted out. Compare the normal and short circuit conditions. If a total short occurs across R2, the only effective resistance in the circuit is R1, for R2 is completely bypassed. Full source voltage is now dropped across R1. The table to the right of the circuit compares normal and abnormal conditions in the circuit.



	Normal	Shorted
E_S	50v	50v
E_{R1}	20v	50v
E_{R2}	30v	0v
R_T	25Ω	10Ω
I_T	2a	5a
P_{R1}	40w	250w
P_{R2}	60w	0w
P_T	100w	250w

The large increase in P_{R1} under short-circuit conditions indicates that R1 would probably burn out very quickly.

Complete the table given below for the circuit shown.



	E_{R1}	E_{R2}	R_T	I_T	P_{R1}	P_{R2}	P_T
Normal				1a			75w
R1 short		75v				112.5w	
R2 short			25Ω			0w	225w

- -

	E_{R1}	E_{R2}	R_T	I_T	P_{R1}	P_{R2}	P_T
Normal	25v	50v	75Ω	1a	25w	50w	75w
R1 short	0v	75v	50Ω	1.5a	0w	112.5w	112.5w
R2 short	75v	0v	25Ω	3a	225w	0w	225w

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9. Indicate how a short circuit would affect the following values. Use arrows as shown to indicate increase (↑), decrease (↓), or remain the same (→).

   a. total resistance ____
   b. current ____
   c. total power ____
   d. source voltage ____

(a. ↓; b. ↑; c. ↑; d. →)

---

10. Short circuits can be located by making either voltage or resistance measurements.

    Select the meters which you might use to find a short circuit.

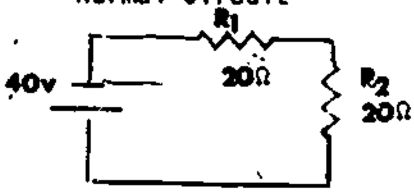
    ___ a. voltmeter and ammeter
    ___ b. ohmmeter and ammeter
    ___ c. voltmeter and ohmmeter

(c) voltmeter and ohmmeter

11. Let's see how you would use a voltmeter to find a short.

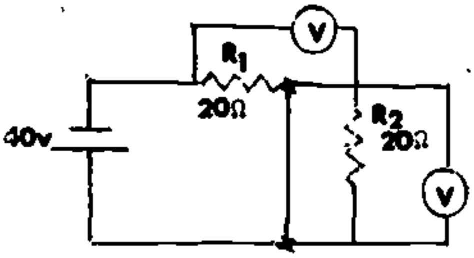
Examples:

Normal Circuit



In this circuit, the voltage drop across each resistor would be 20v, and the sum of the voltage drops would equal E_a.

R2 Shorted



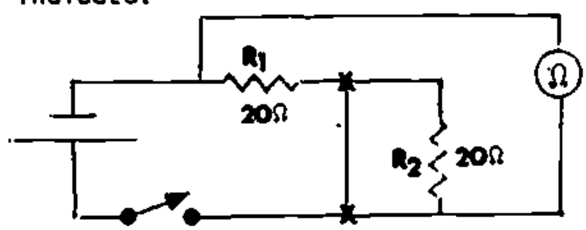
With R2 shorted as indicated, a voltmeter placed across R1 would indicate 40v, the applied voltage. When placed across the shorted component, the voltmeter would indicate 0 volts indicating that R2 has been shorted.

A voltmeter placed across a shorted component would indicate ____ volts.

(0)

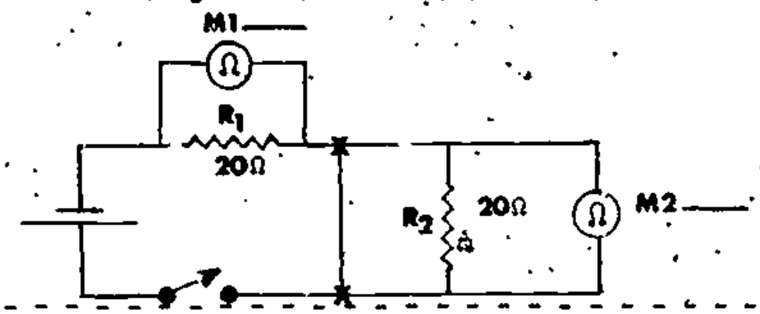
12. An ohmmeter placed across a short circuit indicates 0 resistance.

What would the ohmmeter indicate?



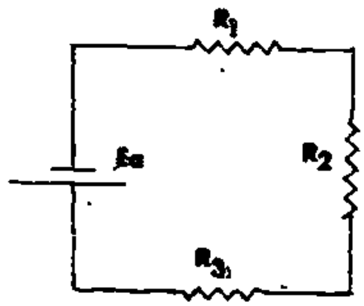
(20Ω)

13. Place meter readings beside each meter in the circuit below.



(M1 = 20Ω; M2 = 0Ω)

14. Compare the table of ohmmeter and voltmeter readings taken from this circuit under normal and abnormal conditions.



	Normal	Abnormal
E_a	75v	75v
R_T	75Ω	50Ω
R_1	25Ω	25Ω
R_2	25Ω	25Ω
R_3	25Ω	0Ω
E_{R1}	25v	37.5v
E_{R2}	25v	37.5v
E_{R3}	25v	0v

State the trouble that exists in the circuit to cause the abnormal readings. ______________________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 14

R3 is shorted

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 18. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 14 AGAIN.

15. As you have learned, a short circuit can cause components to burn up. To prevent this, a safety device called a fuse is installed to protect against excessive ______________.

___ a. current flow.
___ b. source voltage.
___ c. resistance.

(a. current flow)

16. A fuse is made of materials which have a very low resistance and melting point.

Because of the low melting point, excessive circuit current will cause the fuse to:

___ a. drop much of the applied voltage to prevent source damage.
___ b. open, thus preventing damage to other circuit components.

(b) open, thus preventing damage to other circuit components

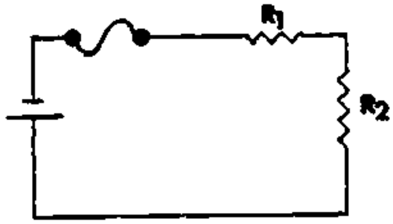
17. The schematic symbol for a fuse looks like dots with a sine wave between them. The abbreviation for the fuse is F1, F2,, etc.

Select the schematic symbol for a fuse.

___ a. C1   c. R1
___ b. L1   d. F1

(d) F1

18. In the circuit illustrated below, the purpose of the component located between the negative terminal of the source and RI is to:



___ a. allow greater current flow through RI.

___ b. open the circuit in the event of excessive current flow.

___ c. increase the total resistance of the circuit.

___ d. drop some of the applied voltage and prevent damage to R2.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 18

b. open the circuit in the event of excessive current flow

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 24. OTHERWISE, GO BACK TO FRAME 15 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 18 AGAIN.

19. The other type of problem which may occur in a circuit is an open circuit or open. This is just what the name indicates, a break which prevents current flow in the circuit. You just saw that this is true because the fuse opens the circuit in the event of excessive current.

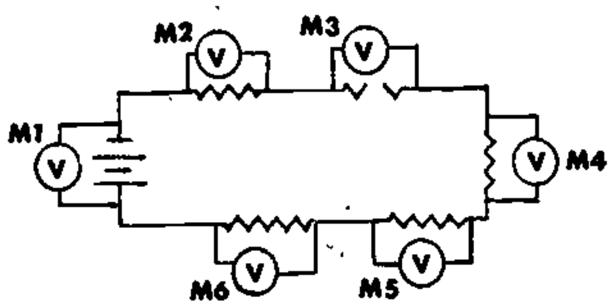
Shipboard equipment, because of the continuous vibration from the engines and the severe shock of firing the ship's guns, is very often troubled by open circuits.

Define an open circuit in your own words. ____________________

(any break which stops current flow)

20. Since no current flows in a series circuit which has an open, no voltage is dropped across the normal components. Full source voltage can be measured across the open in the circuit just as you measure the source voltage across an open switch.

Circle the meters which will indicate source voltage.



(M1 and M3)

21. As you have probably already guessed, you can use the voltmeter to locate an open in a circuit, but you can also use the ohmmeter.

An ohmmeter placed across a resistor and reading infinity will indicate:

___ a. a shorted resistor.
___ b. an open resistor.

- -

(b) an open resistor

22. A voltmeter placed across a blown fuse will indicate __________ __________.

- -

(source voltage)

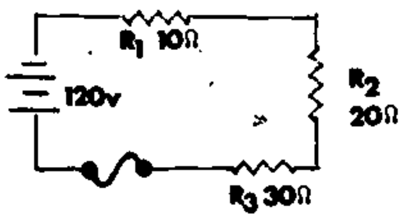
23. An ohmmeter placed across a blown fuse will indicate __________.

- -

(infinity)

ERIC Full Text Provided by ERIC

24. Using the ohmmeter and voltmeter readings in the table, determine the faulty component in the circuit illustrated by this schematic:



	Normal	Abnormal
E_a	120v	120v
λ_T	60Ω	∞
R_1	10Ω	10Ω
R_2	20Ω	∞
R_3	30Ω	30Ω
E_{R1}	20v	0v
E_{R2}	40v	120v
E_{R3}	60v	0v

____ a. R1 open

____ b. R2 open

____ c. R3 open

____ d. F1 open

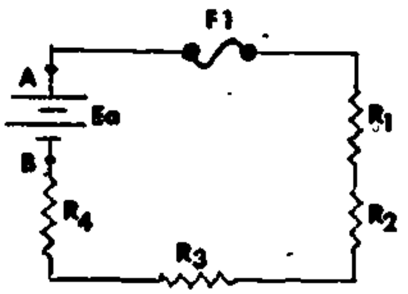
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 24

b. R2 open

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 25. OTHERWISE, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 24 AGAIN.

25. From the table of readings, indicate the faulty component or components.



	Normal	Abnormal
E_a	300v	300v
R_T (A to B)	100Ω	∞
R_1	10Ω	10Ω
R_2	25Ω	25Ω
R_3	25Ω	25Ω
R_4	40Ω	0Ω
E_{R1}	30v	0v
E_{R2}	75v	0v
E_{R3}	75v	0v
E_{R4}	120v	0v
E_{F1}	0v	300v

___ a. F1 and R1 open

___ b. F1 and R2 open

___ c. R1 and R4 open

___ d. F1 open because of R4 short

___ e. F1 open because of R3 short

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 25

d. F1 open because of R4 short

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK AND REVIEW FRAMES 1 THROUGH 24. IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.

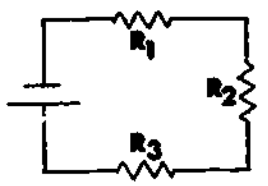
SUMMARY
LESSON V

Troubleshooting Series Circuits

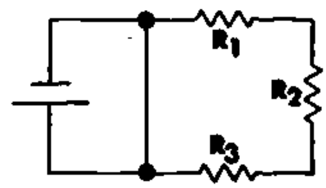
The two general types of problems you will meet in electrical or electronic equipment are short circuits and open circuits.

A short circuit is an unintentional current path. Such a defect always reduces the resistance in the circuit and therefore increases circuit current. Some common causes of a short circuit are broken or cut insulation; loose tools, solder, pieces of wire, etc., left on (or in) equipment; or dirt, salt water, filings, etc., around connection points and terminals.

A direct short occurs when a conducting material forms a path of nearly 0 resistance between the terminals of a source.



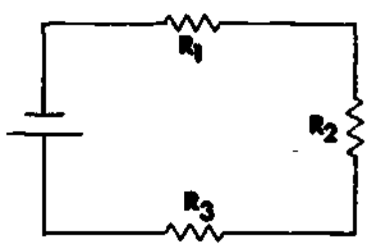
NORMAL



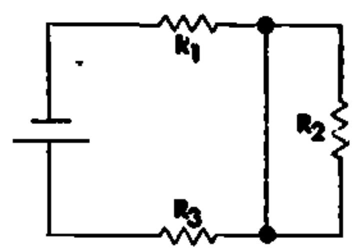
DIRECT SHORT

The large current which results will damage either the source or the wiring very quickly, and this damage will usually open the circuit and stop the current. The name short circuit is derived from the electrically shorter circuit provided by the accidental path.

A partial short bypasses only part of the normal load resistances in a circuit. Such a short reduces current through part of the circuit which is bypassed, but increases current in all the other parts of the circuit.



NORMAL

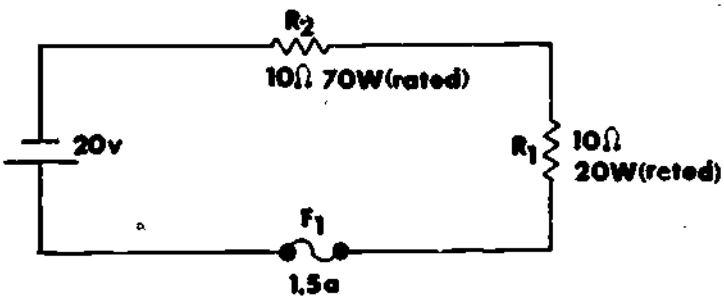


PARTIAL SHORT

In the partially shorted circuit, there will be no voltage drop across R2 because of the short, so R1 and R3 will drop the entire source voltage. The increase in current which results from the lower total resistance is likely to damage one of the other components in the circuit.

A way to eliminate or at least reduce the damage to components caused by a short circuit is to place a fuse in the circuit. A fuse is a safety device which burns out when the current through it is too large. Fuses are connected in series with the circuits they protect, and are rated in amperes for the largest current they will carry without blowing (opening).

This schematic diagram shows a fuse ( ) used to protect a circuit.



The normal 1 ampere of current flow is less than the 1-1/2-ampere rating of the fuse, so it will not blow the fuse. If R1 were to short out (0 ohms), current would rise to 2 amperes and the fuse would burn out, thus stopping current flow and protecting R2 and the source from damage.

The other circuit fault to be discussed here is the open circuit. An open switch or a blown fuse open a circuit when safety or convenience require it to be open, but unwanted opens also occur. These are often caused by dirt or corrosion on switch contacts, loose or broken wires, or burned-out components.

To troubleshoot a circuit means to locate a fault in the circuit. The most widely used tool for troubleshooting is a multimeter like the one you use in this course. Shorts or opens can be found using either a voltmeter or an ohmmeter. In searching for a shorted part with either meter, you look for an abnormally low reading. Always remember not to use an ohmmeter on a live circuit when you troubleshoot.

Open components are found by looking for an abnormally large voltage or resistance. An open component in a series circuit will read full source voltage if it is energized or it will read infinite resistance if the ohmmeter is used (dead circuits only!).

NOW YOU MAY EITHER TAKE THE PROGRESS CHECK OR STUDY ANY OTHER OF THE RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR INSTRUCTOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR INSTRUCTOR AND ASK TO TAKE THE MODULE TEST.